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Project Delivery Configuration for Satisficing Building Energy Renovation Activities

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Author's Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

Niall Dunphy

Abstract

The essence of this thesis is a transdisciplinary exploration of value within building energy renovation projects. How it is understood, from which activities it is derived, who is responsible for its creation, how it is distributed. The temporary multi-firm configurations[1] that coalesce to deliver such renovations are central to the research. Adopting a life cycle perspective and selecting three primary measures of success – energy savings, avoided greenhouse gas emissions[2] and financial return – the thesis examines how achieving these objectives can be incentivised. It looks at how project success (and increased renovation market capacity) can be encouraged through delivering adequate value, in whatever shape that may take, to key stakeholders in the value chain(s) associated with buildings and their renovation.

This research required understanding of both construction activities, and the groups of entities that deliver energy renovations. This is achieved through the application of a transdisciplinary methodology that combines engineering and social scientific knowledge. In addition to knowledge about the construction activities, it requires the use of methodological understandings and approaches from the human and social sciences which are used to theorise, conceptualise, contextualise, and actualise the required research. This thesis posits that these groups are fundamentally social constructs, albeit guided by 'rules' in the form of contracts or governmental regulations. Acknowledging the social nature of the configurations, the research in the thesis draws on an anti-foundationalist ontology, and adopts a social-constructivist epistemology. Accordingly, in addition to significant review of the literature, qualitative data gathering and analysis techniques are used to understand the objectives of building energy renovation projects, the nature of the groups

[1] A type of project based organisation comprised of both formal and informal arrangements.
[2] Greenhouse gas (GHG) emissions have a strong relationship with energy, as energy consumption accounts for the vast majority of such releases. However it is not necessarily a direct relationship – as different energy sources result in different quantitates of such emissions. In certain scenarios changes in the source of energy could therefore result in reductions in GHG emissions while energy consumption remains the same or even increase (or *vice versa*).

of stakeholders that deliver them, and the workings of the value chains within which the stakeholders operate.

To understand construction and related functions involved with renovation projects, the lifecycle of a building was disaggregated to identify all the various activities which occur throughout a building's life. These undertakings were then grouped into six phases of activity, which are labelled hubs of activity. This model was used to map stakeholders across the lifecycle of a building, this identification and characterisation facilitated an in-depth engagement with key stakeholders throughout the value chains that deliver building energy renovation. This engagement constituted face-to-face semi-structured interviews *i.e.*, comprising open-ended questions which allow respondents to tell 'their story'. The interviews were recorded and transcribed to form a valuable qualitative dataset. The interview transcripts were thematically analysed as a means of understanding stakeholder interactions, determining how key stakeholders define 'value' and to exploring 'flows' through the energy supply chain, including value, practices, norms and influences.

The need to develop business models for building renovation which offer adequate value (*i.e.*, satisfice) for stakeholders is recognised, as is the imperative that key stakeholders be incentivised to align their objectives with that of the energy renovation project. Simon (1955, 1956) coined the term 'satisfice', a combination of the words satisfy and suffice, for an alternative decision-making strategy that seeks to find an acceptable choice under a limited set of considered options – see Section 8.1.4 for a fuller of description of satisficing.

Findings from the interviews are presented with an exploration of the stakeholder relationships, power flows, drivers, conflicts, and potential synergies within building energy renovation projects. These findings are then discussed in the context of configuring project delivery of building energy renovation activities, such that the interests of all (important) stakeholders are satisficed and that they are appropriately incentivised to align their objectives with that of the project and in doing so deliver successful renovation projects.

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Acronyms

AIA	American Institute of Architects
BIM	Building Information Model(ling)
BOO	Build-Own-Operate
BOQ	Bill of quantity
BOT	Build-Operate-Transfer
BREEAM	Building Research Establishment Environmental Assessment Method
BSI	British Standards Institution
C&D	Construction and Demolition
C2C	Cradle-to-cradle
C2G	Cradle-to-gate
CAQDAS	Computer-assisted qualitative data analysis software
CBA	Cost benefit analysis
CEN	European Committee for Standardization
CER	Commission for Energy Regulation
CF	Carbon Footprint
CHP	Combined Heat and Power
CIRIA	Construction Industry Research and Information Association
CM	Construction Management
CM-aR	Construction Management at Risk
CO_2e	GHG expressed in terms of CO_2 equivalence
CPPU	Cleaner Production Promotion Unit
D&C	Design and construction
DB	Design-Bid
DBB	Design-Bid-Build
DBFM	Design-Build-Finance-Operate
DECC	Department of Energy and Climate Change (UK)
DECLG	Department for Environment, Communities & Local Government
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
DIBt	Deutsches Institut fur Bautechnik
DPER	Department of Public Expenditure and Reform (IE)
DPP	Discount payback period
EAC	Equivalent annual costs
EC	European Commission
EED	Energy Efficiency Directive 2012/27/EU
EP	European Parliament
EPBD	Energy Performance of Buildings Directive (recast) 2010/31/EU
EPC	Energy Performance Contracting
EPD	Environmental Product Declarations
EPI	Environmental Policy Integration
ESCo	Energy Service Company
ETAP	Environmental Technologies Action Plan
EU-27	European Union (prior to accession of Croatia)
FP7	EU Seventh Framework Programme for Research and Technological Development
GDP	Gross Domestic Product
GHG	Greenhouse gas
GPP	Green public procurement
GWP	Global warming potential

H2020	EU Horizon 2020 Programme for Research and Innovation
HIA	Housing Industry Association, Australia
HQE	Haute Qualité Environnementale
HVAC	Heating, ventilation and air conditioning
IEA	International Energy Agency
IIR	Internal rate of return
ILCD	International Reference Life Cycle Data System
IPA	Interpretative phenomenological analysis
IPCC	Intergovernmental Panel on Climate Change
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
JRC-IES	Joint Research Centre - Institute for Environment and Sustainability
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCCA	Life Cycle Cost Analysis
LCEA	Life Cycle Energy Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LCT	Life Cycle Thinking
LDO	Lease-Develop-Operate
LEED	Leadership in Energy and Environmental Design
MMD	Multiple Decision Diagram
NPV	Net Present Value
O&M	Operations and maintenance
OECD	Organisation for Economic Co-operation and Development
PACE	Property assessed clean energy
PAS	Publically available specification
PBO	Project based organisation
PCF	Product carbon footprint
PCR	Product category rules
PPP	Public-private partnership
PPS	Product-service systems
REA	Resource-event-agent
RIBA	Royal Institute of British Architects
RRD	Recovery, recycling and disposal
sej	Solar emjoule
SETAC	Society of Environmental Toxicology and Chemistry
SME	Small to medium-sized enterprise
STOF	Service, Technology, Organisation, Finance
TFMC	Temporary multi-firm configurations
UCC	University College Cork
UN	United Nations
UNEP	United National Environmental Program
UNFCC	United Nations Framework Convention on Climate Change
VCA	Value chain analysis

1 Introduction

"What gets us into trouble is not what we don't know. It's what we know for sure that just ain't so" – Mark Twain

This chapter introduces the thesis, detailing the overarching aim of the research and exploring the background of the work and the context which frames the study undertaken. The key objectives of the research are presented and discussed and an outline of the principal contributions of the work presented.

1.1 Introduction to the chapter

This thesis seeks to gain an understanding of the workings of those configurations of organisations that join together – informally and formally, implicitly and explicitly – to deliver construction projects, such as energy-focussed renovations of buildings.

This knowledge will be used to devise a conceptual model, which includes the various actors involved in construction activities and enables tailored representations for individual projects. Use of this artefact can then form the basis of configuring project delivery of building energy renovation activities, such that the interests of (important) stakeholders are satisficed. Satisficing implies employing a decision-making strategy which attempts to meet criteria for sufficiency or adequacy, (in this case as agreed by multiple stakeholders) rather than to identify (possibly subjective) optimal solution(s) (March & Simon, 1958; Simon, 1956)

In addition to these introductory remarks, this first chapter contains six additional sections. Section 1.2 comprises an overview of the background and context that frames the study. Section 1.3 then presents the objectives of the research, outlining the problem statement, the statement of purpose and the accompanying research questions. Following the discussion on the reasons for the research, Section 1.4 briefly introduces the methodology, which will be discussed later in the thesis. Section 1.5 outlines the contributions of the work presented. The structure of the thesis including an overview of the approach taken is offered in Section 1.6. Finally, Section 1.7 concludes with a recap of this opening chapter's content.

1.2 Background and context

1.2.1 Background to the research

At the time of writing the author is employed within the UCC School of Engineering, where he leads a research group called the Cleaner Production Promotion Unit. This inter-disciplinary group comprising researchers of a diverse academic background, operates at the intersection of the social sciences with science and engineering. The group conducts research on the sustainability of socio-technical systems, with a particular focus on energy and the built environment.

This thesis is the product of work primarily conducted as part of the Carbon Neutral Buildings Project and funded by a private donor through the Cork University Foundation. Prof. Karsten Menzel, Chair of IT in AEC[3], who served as a leading principal investigator on the project, acted as supervisor of this PhD. The thesis also developed through work on a number of relevant EU projects where the author was either project co-ordinator[4] or UCC principal investigator[5, 6,] particularly within the UMBRELLA project, which explored business model innovation for energy efficient buildings *i.e.*, high performance new builds and energy renovation of existing buildings.

1.2.2 Context and significance

Why renovate to improve the energy performance of buildings?

It is widely acknowledged that buildings and associated construction activities offers

[3] Information Technology in Architecture, Engineering & Construction
[4] ENTRUST: Energy System Transition Through Stakeholder Activation, Education and Skills Development (H2020 2015-2018)
[5] UMBRELLA: Business Model Innovation for High Performance Buildings Supported by Whole Life Optimisation. (FP7 2012-2015)
[6] NewTREND: New Integrated Methodology and Tools for Retrofit Design Towards a Next Generation of Energy Efficient and Sustainable Buildings and Districts (H2020 2015-2018)

significant societal benefits – the construction industry, for instance provides 5-10% of employment, accounts for 5-15% of gross domestic product (GDP), and delivers the homes, workplaces and infrastructure necessary for everyday life (Huovila, Ala-Juusela, Melchert, & Pouffary, 2007). However, the built environment also has significant detrimental aspects, it is for example responsible for up to two-fifths of energy consumption and accounts for *ca.* one-third of releases of climate changing gases (Cheng, Pouffary, Svenningsen, & Callaway, 2008; European Commission, 2010). Given this significant share of global energy use and greenhouse gas (GHG) emissions, buildings have a significant contribution to make in achieving climate change objectives. Buildings are seen as representing one of the largest sources of unrealised potential cost effective energy savings and GHG reductions, more perhaps any other single domain within Europe (European Commission, 2011a; Staniaszek, Bruel, Fong, & Lees, 2013).

However, buildings are long-life products, with for example a replacement rate for housing stock of 0.25% or less observed in the Netherlands, France and the United Kingdom (Thomsen & van der Flier, 2009). While these seem to be extremely low figures, Thomsen and van der Flier comment that while "*calculations are not robust and only provide a modest indication, but they accentuate that the average lifespan of the existing stock will be much longer than usually expected*" (Thomsen & van der Flier, 2009, p. 653). The long-life of buildings is illustrated by the estimation that that four-fifths of buildings in the EU, currently in use will still be operational in 2030 (European Commission, 2010), and Kelly's (2009) calculation that 87% of existing British buildings will be still functioning by 2050. This longevity of the building stock means that constructing energy efficient new buildings will form only part of the solution. So while it is important to design, construct and commission new buildings to high standards of energy efficiency, this alone will not be enough – a substantial programme of renovation of existing buildings to improve their energy performance is required, if the ambitious GHG emissions reduction targets for the sector are to be achieved in the coming years (EU, 2008). Indeed, there are a number of significant drivers for improving the energy performance of the building stock, as will be explored below.

Drivers for improved energy performance of buildings

Energy insecurity

Although there had been some existing regulations for energy efficiency in buildings[7], the energy insecurity highlighted by the 1973/74 and 1979/81 oil crises brought energy efficiency to the fore of public policy objectives (Barnes & Barnes, 1999, p. 230 quoted in; Mullally & Dunphy, 2015, p. 52) including for buildings, *e.g.*, Sweden's 1977 energy efficiency supplement to its building standards (SBN 75), providing for minimum k-values for various building components (McCormick & Neij, 2009, p. 6); US Energy Tax Act of 1978 provided federal income tax credits to homeowners for specified energy conservation investments (Gillingham, Newell, Newell, & Palmer, 2004, p. 33).

More recently, these concerns on energy security have been exacerbated by reducing fossil fuels reserves (Owen, Inderwildi, & King, 2010); political uncertainties (Torello & Robinson, 2012); and growing geo-political competition for natural resources (Zweig & Jianhai, 2005). Such concerns have served to intensify public policy efforts to reduce energy consumption.

Climate change

Reducing emissions of, and stabilising the atmospheric levels of, greenhouse gases (GHG)[8] is an increasingly accepted necessity. There is unambiguous evidence by direct observation that global warming is occurring (Solomon *et al.*, 2007) – for instance, Figure 1 below illustrates the temperature rise between 1880 and 2009 (the black curve showing annual average temperatures, the red curve a 5-year running average, and the green bars indicating estimated uncertainty for different periods of the record).

[7] *e.g.,* Standards for insulation materials were introduced in Scandinavian countries from the late 1950s onwards (Laustsen, 2008, p. 14)
[8] Greenhouse gases (GHG) are those gases that while in the atmosphere absorb infrared radiation, thereby contributing to the greenhouse effect *i.e.,* the trapping of heat from the sun in the lower atmosphere. (As GHG emissions are typically expressed in terms of carbon dioxide equivalence CO_2e it is common to see the term 'carbon' used as a synonym for such emissions).

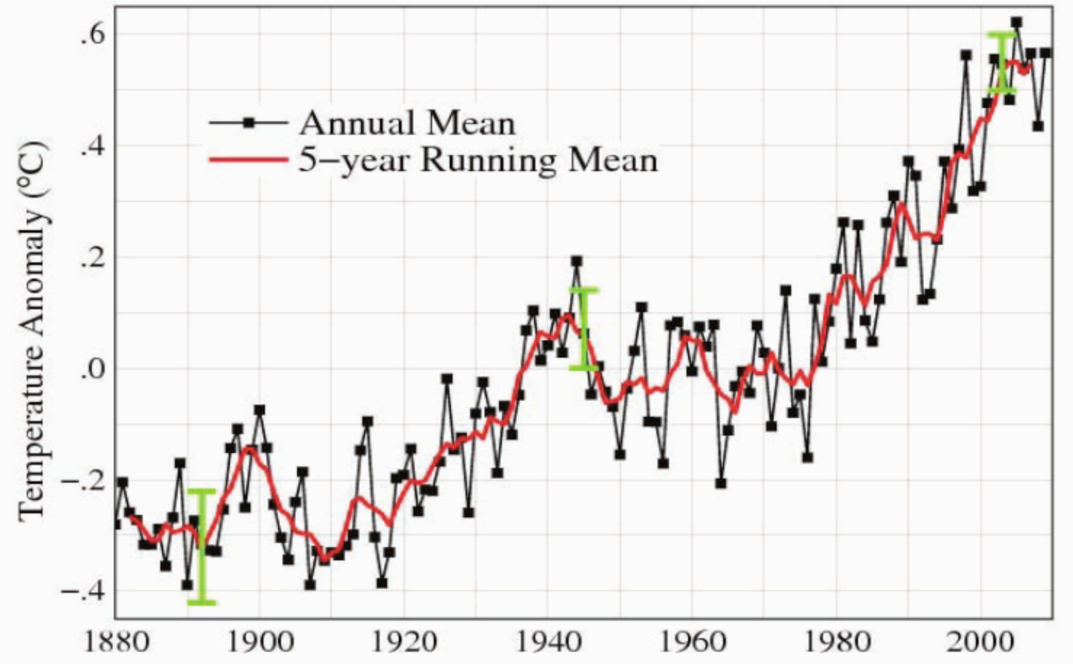


Figure 1: Global surface temperature change 1880-2009 (National Research Council, 2010, p. 39)

Accordingly, scientific arguments have mostly moved on from debates on the existence of climate change (notwithstanding populist political views in certain countries), to the extent of human involvement and its implications, including possible adaption and mitigation strategies (see Helm, Hepburn, & Mash, 2005).

This rise in global temperatures poses significant risks to geological, biological and ecological systems. These risks have the potential to result in a range of catastrophic societal and economic impacts for human society (National Research Council, 2010), some of which are beginning to be observed *e.g.*, water and food insecurity (Hanjra & Qureshi, 2010); increased risk of vector-borne diseases (Semenza & Menne, 2009); enforced migration (Warner, Ehrhart, De Sherbinin, Adamo, & Chai-Onn, 2009); warfare (*e.g.*, Levy, Sidel, & Patz, 2017 posit that drought related desertification was a factor in the Syrian civil war, which commenced in 2011).

Social good

Of course a significant societal and (at least nominally) public policy driver for improved energy efficiency is addressing fuel poverty and temperature-related related morbidity and mortality (Wilkinson, Smith, Beevers, Tonne, & Oreszczyn, 2007) *e.g.*, Levine *et al.* (2007, p.

418) report UK Department of Health data putting the number of winter 'excess' deaths chiefly due to inadequate heating at 30,000 per annum between 1997 and 2005. There is therefore a large amount of social good to be achieved through energy renovation activities, particularly those focused on vulnerable households.

Economic opportunities

There is considerable economic opportunity in energy renovation of buildings, It is estimated that, on average, building energy renovations can achieve 75-80% improvements in energy performance (Maio, Zinetti, & Janssen, 2012, p. 7). The scale of the potential renovation activity is illustrated by Economidou *et al.*'s (2011, p. 9) estimate of c. 25 billion m^2 of useful floor space in the (then) EU-27 plus Switzerland and Norway, with much of it over fifty years old – this is equivalent to the land area of Belgium. Figure 2 below provides an overview of the area distribution of different building types.

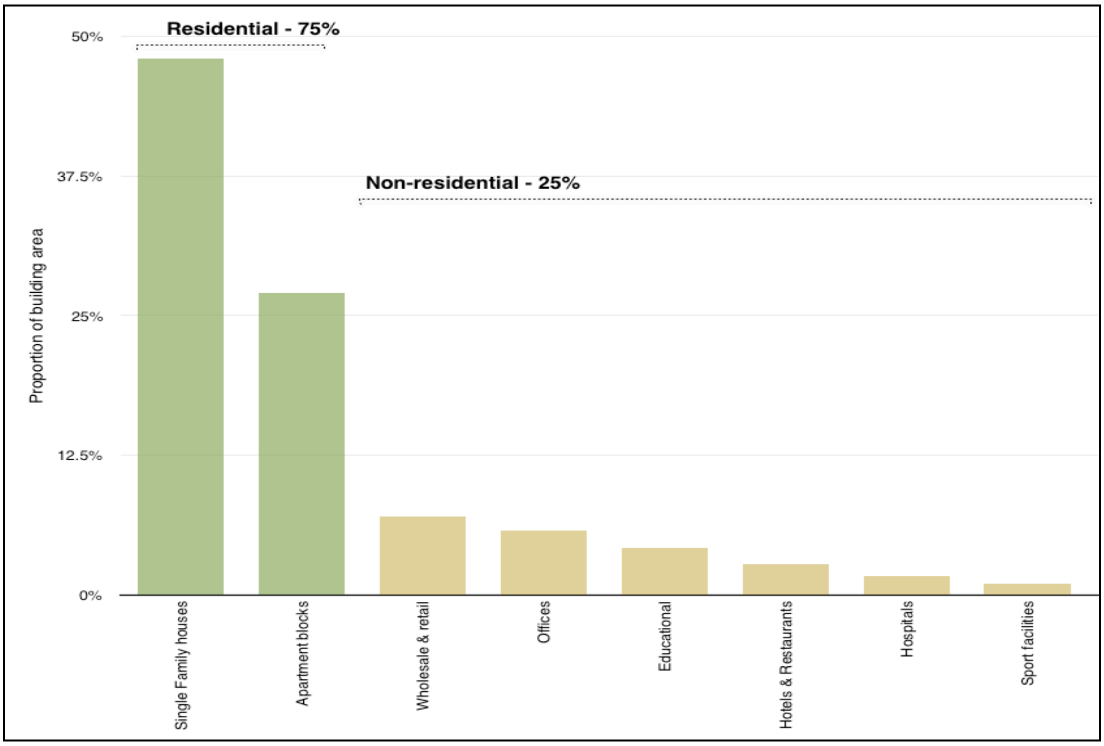


Figure 2: Overview of Europe's building types (derived from Economidou *et al.*, 2011, p. 8)

The Buildings Performance Institute of Europe in an analysis of deep renovation scenarios (EU-27+CH+NO) estimate a potential for net energy costs savings of up to €1,300 billion present value, arising to end users, for an investment of €940bn (present value) over the period to 2050 (Staniaszek *et al.*, 2013, p. 6).

Policy drivers

As would be expected from the energy efficiency and GHG avoidance potential of buildings, there are a large number of public policy initiatives aimed at minimising energy consumption of both new and existing building stock, including: traditional grants (such as the recently ended Warm Front scheme in the UK discussed by Hong, Gilbertson, Oreszczyn, Green, & Ridley, 2009) and innovative payments (*e.g.*, Government bounties to reward building energy efficiency in North China reported by Zhong, Cai, Wu, & Ren, 2009); increasingly more stringent national building codes (as illustrated by Denmark's periodic revision of their codes, referenced by Laustsen, 2008, p. 16); the EU Energy Performance of Buildings Directive (EU, 2010a); green public procurement in respect of buildings (*e.g.*, as indicated in a number of entries in the European Commission, 2016b review of GPP nation action plans); tailored financial products such as: low-interest green loans (*e.g.*, KfW energy renovation loans in Germany, discussed by Baek & Park, 2012); property tax financing (*e.g.*, Property Assessed Clean Energy initiatives in the USA, as discussed by Ameli, Pisu, & Kammen, 2017); utility on-bill financing (*e.g.*, as facilitated by the Power New York Act 2011, reported by Ball, Nadel, & Hayes, 2011).

The challenge

Barriers to renovation

However, notwithstanding the strong societal pressures, regulatory drivers, and associated economic and technical supports, and the competitive investment returns frequently offered by renovation projects (Kneifel, 2010), the level of activity is nowhere near that required to achieve the level of energy savings and GHG avoidance expected of the sector. Despite the considerable potential market size and drivers such as EU mandated energy renovation targets, the European Commission notes that "*Energy efficiency in buildings suffers from underinvestment and numerous barriers*" (2016a, p. 5). For the time being, at least, the level energy-focused renovation of buildings remains too low (European

Commission, 2011a), and the market for such renovation has not realised its full potential.

Table 1 below presents an overview of the types of barriers that hinder energy efficient building intervention take up.

Barrier Categories	Definitions	Examples
Financial costs/benefits	Ratio of investment cost to value of energy savings	• Higher up-front costs for more efficient equipment; • Lack of access to financing; • Energy subsidies; • Lack of internalisation[9] of environmental, health and other external costs.
Hidden costs/benefits	Cost or risks (real or perceived) that are not captured directly in financial flows	• Costs and risks due to potential incompatibilities, performance risks, transaction costs *etc.*; • Poor power quality (i.e., electric supply with voltage, current and frequency values within optimum range), particularly in some developing countries.
Market failures	Market structures and constraints that prevent the consistent trade-off between specific energy-efficient investment and the energy saving benefits	• Limitations of the traditional building design process; • Fragmented market structure; • Landlord/tenant split and misplaced incentives; • Administrative and regulatory barriers (*e.g.,* in the incorporation of distributed generation technologies); • Imperfect information.
Behavioural and organisational inefficiencies	Behavioural characteristics of individuals and organisational characteristics of companies that hinder energy efficiency technologies and practices	• Tendency to overlook multiple small energy conservation opportunities; • Organisational failures (*e.g.,* internal split incentives); • Non-payment and electricity theft; • Tradition, behaviour, lack of awareness and lifestyle; • Corruption.

Table 1: Taxonomy of barriers to energy efficient building technologies (Levine *et al.*, 2007, p. 419 derived from Grubb & Wilde 2005 p. 16)

[9] The OECD define cost internalisation as the "incorporation of negative external effects, notably environmental depletion and degradation, into the budgets of households and enterprises by means of economic instruments, including fiscal measures and other (dis) incentives".

As can be seen from the above table there is a wide range of barriers, which impede the initiation and delivery of building energy renovation. Many of these barriers are associated with the value propositions that renovation offer stakeholders, including perceived risk, lack of knowledge, split incentives, solution lock-in, behavioural inertia and market capacity (Morrissey, Dunphy, & MacSweeney, 2014). Overcoming these barriers to greater renovation activity requires addressing the issue of insufficient value accruing to key stakeholders – this can only be done by understanding the web of stakeholders involved in building renovations, how they contribute to the overall activity, their influence on other stakeholders, and critically the (financial and non-financial) value(s) they seek to capture in return for their contributions.

Understanding renovation delivery

Renovation projects, as with all construction works, are delivered by dynamic and transitionary supply chains (a feature of the construction sector) that coalesce into a form of project based organisation, which this thesis terms temporary multi-firm configurations (TMFC) (Dunphy, Morrissey, & MacSweeney, 2013a). These TMFCs typically display a high level of complexity compared to the more linear based models of traditional manufacturing processes and this is evident in the wide diversity of relationships found within the configurations (Dunphy & Morrissey, 2015). TMFC component-businesses relate through procurement and subcontracting arrangements of various degrees of formality consisting of a web of contracts and/or informal commitments, which can involve both multilateral and bilateral contracts and range from formal detailed contractual arrangements (where the contracted parties play an integral part of the project, perhaps with performance-based consideration) to informal mercantile transactions (wherein the seller may not even appreciate that they are contributing to the completion of particular works and that they are implicitly a component of the associated TMFC) (Dunphy, Morrissey, & MacSweeney, 2013b).

1.3 Objectives

1.3.1 Problem Statement

There is international agreement that GHG atmospheric concentrations should be stabilised so as to prevent (further) dangerous interference with the climate (UN, 1994). The built environment, which accounts for a large proportion of global energy consumption and associated GHG emissions offers greater potential for energy savings and greenhouse gas reduction than any other single domain. Yet, despite the significant number of regulatory, economic, social and environmental drivers, renovations leading to reduced GHG intensity are occurring at too low of a rate to deliver the required reductions in emissions.

A deeper understanding of the various interactions and value flows that take place within the *ad hoc* collection of stakeholders that deliver energy renovation projects can contribute to increasing renovation activity through facilitating the development of business models which deliver sufficient value for all stakeholders *i.e.*, yielding sufficient financial return (and other values) for project promoters (thereby addressing market demand) while also providing the various contributing businesses adequate value in return for their contribution (addressing market capacity).

1.3.2 Statement of Purpose and Research Questions

The purpose of this thesis is to explore the value propositions of stakeholders associated with building energy renovations, *i.e.*, the entities that make up the dynamic multi-firm configurations, which deliver such projects. This acquired understanding will be used to develop a conceptual model for describing and representing the relationships and values (including non-monetary values) within a project based enterprise, specifically within building energy renovation projects. It is anticipated that such a model will enable more informed decision-making by prospective stakeholders and contribute to the satisfying or perhaps more accurately 'satisficing'[10] of the all those involved in such projects. To work towards this understanding and development of a model the following research questions are addressed:

- Who are the various stakeholders involved in delivering energy renovation projects?
- What functions do stakeholders play in building energy renovation projects and how do they interact with one another?
- What financial and non-financial 'value(s)' do the stakeholders seek from their involvement in building energy renovation projects?
- How can these project values be better understood, so as to contribute to increasing building energy renovation activity?

1.4 Research methodology

This thesis posits that understanding the multi-firm configurations which deliver energy renovations, in addition to knowledge about the construction activities, requires the use of methodological understandings and approaches from the human and social sciences to theorise, conceptualise, contextualise, and actualise the required research. The research philosophy and strategies underpinning the research in this thesis are detailed and discussed extensively in Chapter 2. To summarise the research approach adopted for this thesis – it is a generic qualitative methodology (albeit one informed by grounded theory), which uses literature review, in-depth face-to-face interviews, and thematic analysis as its principal methods of data collection and analysis.

1.5 Contributions of this work

1.5.1 Methodological approach

The research presented in this thesis is a novel trans-disciplinary study, using and

[10] As explained earlier, satisficing implies employing a decision-making strategy which attempts to meet criteria for sufficiency or adequacy, as agreed (implicitly or explicitly) by multiple stakeholders, rather than to identify a (possibly subjective) optimal solution (*e.g.*, Hoyningen-Huene, 2008)

combining approaches from a number of academic disciplines including engineering, sociology, and business. The methodology applied in this research, and the methodological explorations underpinning it are themselves useful contributions and can be adopted to other studies both within the construction domain and more widely.

1.5.2 'Hubs of Activity' model

An important contribution of this thesis is providing a conceptual model for the life cycle consideration of the activities associated with construction projects (Dunphy et al., 2013b, 2013a). The Hubs of Activity model was developed though a detailed review of the literature, and corroborated and refined through a comprehensive engagement with industry stakeholders in nine European countries, comprising actors from right across the value chains associated with building renovation. The model offers a value approach to systematically describe building energy renovation activities. The model makes a number of significant contributions: A full characterisation of project activities across an extended time-horizon allows for more in-depth consideration of value generation in the context of specific lifecycle focal points or hubs. The applied cradle-to-cradle perspective allows for better integration of sustainability and financial concerns.

1.5.3 Multi-dimensional perspective on value

The thesis provides a novel application of value analysis (Dunphy *et al.*, 2013a; Morrissey *et al.*, 2014). Using a value chain characterisation of the activities in the hubs of activities model, this thesis builds upon concepts from business model literature (see in particular Osterwalder, 2004) to conceptualise the flow of multi-dimensional value(s) between the different stakeholder entities. It facilitates understanding the materials and monetary flows within supply chains, and the value interactions between stakeholders. Such understanding is vital for creating novel business models (Boo, Dallamaggiore, Dunphy, & Morrissey, 2016; Dunphy, Boo, Dallamaggiore, & Morrissey, 2016), developing inclusive approaches for designing renovations (Ferrando *et al.*, 2016), optimising value chains for performance (Dunphy & Morrissey, 2015), increasing the long-term capacity of the sector, and growing the level of building energy renovation activity.

1.5.4 Life cycle perspective of buildings (and building performance)

A further contribution of this work is a presentation and clarification on the appropriate application and worth of the differing perspectives on life cycle as regards buildings. Life cycle energy and greenhouse gas emissions are disaggregated as a means of developing a fuller understanding of the concepts (Dunphy & Henry, 2012b). This disaggregation, and the perspectives it enables, are then used to consider the life cycle performance of building energy renovations in the various ways stakeholders might consider such performance, which facilitates the identification of performance risks (Dunphy & Henry, 2012a) and the selection of most appropriate renovation solutions (Dunphy, Little, & van der Krogt, 2012).

1.6 Structure of thesis

This thesis is comprised of eight chapters, the first of which is this introductory section, which provides the background and motivation for the work. Chapter two considers the research philosophy applicable to the research outlined in this thesis and outlines the research methodology and approaches to be applied. The chapter explores the philosophical and theoretical background to the research and details the approaches and strategies behind the selection of particular research methods and techniques for data collection and analysis. The third chapter takes a life cycle perspective on buildings – ideas and methodologies associated with consideration of the life cycle of buildings are reviewed. A particular focus is placed on energy consumption and associated emissions, over buildings' whole life. This concept of life cycle, encompassing activities both before and after the manufacture of goods, provision of services or in this case the construction of a building is explored. The individual life stages of a building are characterised and explored. Three primary measures of life cycle performance of buildings and/or building renovation projects are introduced and reviewed (cost, energy, greenhouse gas emissions), and methods for their calculations examined *viz.*, life cycle costing, life cycle energy analysis, greenhouse gas life cycle inventory.

In chapter four the concepts relating to the value creation, delivery and capture are introduced and relevant literature reviewed. Acknowledging DaSilva and Trkman's (2013) observation on the discrepancy between the importance attributed to the term, and the low level of clarity of its meaning, the chapter explores the range of understandings of the 'business model' concept ranging from those that consider it a generic term to mean the way in which a company does business, *e.g.*, Gebauer and Ginsburg (2003) to those that focus on the model aspect of the term, and use it to mean the realisation of a representation of a company's business logic *e.g.*, Osterwalder (2004) – the latter end of this continuum of perspectives being of most relevance to the work of this study.

The fifth chapter details the work undertaken to develop an understanding of energy renovation project delivery. A model for the life cycle of a generic construction project is presented, comprised of six stages or so-called hubs of activity. A description of the stakeholders located around each hub and their interactions is presented. Details of in-depth engagement with a wide variety of energy renovation stakeholders from across Europe is presented. The grounded approach taken with the informants is outlined and the qualitative assessment (thematic analysis) of the interview transcripts described.

Chapter six seeks to present insights on the *Hubs of Activity* model which emerged from the analysis of the interview. A mapping exercise was carried out for each *Hub of Activity,* which detailed the actors, influences, and outcomes associated with, and identified the key relationships within each hub or stage. This information is then used to develop illustrative power-interest matrices reflecting the relationships of the key stakeholders at each stage.

The seventh chapter comprises a presentation and discussion of the key findings arising from the thematic analysis of the respondents' interview transcripts. Five principal themes emerged from the analysis, namely: knowledge; marketplace; finance and business planning; project; society and policy.

This eighth and final chapter draws together the key findings from the research, examining their significance and implications for satisficing building energy renovation activities. The limitations of the study are reviewed, recommendations forwarded for the increase of renovation activity, and suggestions made for the further direction of research in this area.

1.7 Conclusion

This initial chapter provided the background to this study, particularly illustrating the importance of reducing GHG emissions and the potential contribution of the built environment to such reductions. An overview of the context of the study was presented and the problem statement set out. The structure of the thesis was outlined containing within it, an overview of the approach taken in the study. The next chapter reviews ideas and methodologies associated with consideration of the environmental aspects of buildings, focusing especially on energy consumption and associated emissions, over their whole life or life cycle. This concept of life cycle, encompassing activities both before and after the manufacture of a good, provision of a service, or in this case the construction of a building and methodologies for measuring environmental impact from this perspective are explored, and their applicability to the built environment discussed.

2 Methodology

"The whole of science is nothing more than a refinement of everyday thinking" – Albert Einstein

This chapter considers the research philosophy applicable to the research outlined in this thesis and outlines the research methodology and approaches to be applied. In essence, the chapter will explore the philosophical and theoretical background to the research and to paraphrase Crotty's (1998, p. 3) view of methodology, will detail the strategies, plans, and design processes which guided the selection of particular research methods and techniques for data collection and analysis.

2.1 Introduction to the chapter

The hegemonic approach to research in the engineering and natural sciences is the so-called 'scientific method'. Although it arguably does not of itself constitute a single methodology and there is no operational definition of the scientific method, it does represent a particular 'logic of inquiry' (Schwandt, 2007, p. 191). To paraphrase Moses and Knutsen (2012, p. 19), the scientific method can be said to involve planned and structured observation[11], careful recording of observations, and great deal of reasoning to make sense of the results. Weatherall (1968, p. 17) summarises the scientific method as the bringing together facts and ideas, in a cyclic process of reasoning and observation used to generate and test proposed hypotheses and/or theories[12]. It is succinctly defined by the Oxford Dictionary of English as a:

> *"method of procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses"* (OUP, 2010).

[11] Through passive observation or via controlled experimentation
[12] This inherently requires proving causal links, it is noteworthy that this may be problematic for example in case of indeterminism of real complex phenomena/systems as suggested by Prigogine (see *e.g.*, Prigogine & Stengers, 1997) – see also reference to chaos theory in footnote 16

Thus, the traditional scientific method can be seen to be based very much on a world view that the world we observe is 'real' and 'separate' *i.e.*, it exists independent of our senses and it is capable of being objectively described and interpreted (Hammond & Wellington, 2013, p. 120; Moses & Knutsen, 2012, p. 29). From this perspective, it is not difficult to see why in-depth explorations of the philosophy, theories and concepts underpinning research approaches are not overly common in the engineering and natural sciences. In this regard, it is not uncommon for such studies to give quite perfunctory consideration to methodological issues – in the implicit view that the philosophical basis of the research does not need to be examined, if it is following a so-called scientific method[13]. Weinberg (1995) goes as far as saying that most scientists do not understand the scientific method, they just do – likening it to someone riding a bicycle: "*if they think too much about it they are likely to fall off*". However, if there is no one scientific method and alternative approaches to scientific inquiry exist – it would appear that some consideration of the methodology choices within a research study are warranted, even where adherence to scientific method is claimed. This chapter aims to explore the philosophy and concepts applicable to such a research study and to design a methodology strategy for the research to be undertaken.

This thesis posits that the various entities whose activities combine to deliver building energy renovations are essentially communities of interacting humans – in other words social systems. Understanding these communities therefore requires the use of methodological understandings and approaches from the human and social sciences[14] to theorise, conceptualise, contextualise, and actualise the required research. While traditional scientific method approaches have been applied in the social sciences, and while

[13] Notwithstanding that some (*e.g.*, Bauer, 1992, *pp.* 19–41; Wivagg, 2002) consider the scientific method to be a fable, albeit one that makes a nice ideal

[14] There is a school of thought (see *e.g.*, Campbell, 1998; S. M. Rosen, 2015) that the understanding of the term 'science' can be expanded to include other areas of knowledge such as the humanities and social science making it equivalent to the German term 'Wissenschaft'.

for some it may be seen as the only legitimate means of gaining knowledge[15], it is not the only possible research philosophy for exploring humans and the social world. This chapter will examine which is the most appropriate philosophy and strategy to be adopted for this research study.

Crotty (1998, p. 3) defines methodology as "*the strategy, plan of action, process of design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes*" and contrasts this with methods, which he describes as the means used to gather and analyse data relating to a research question. Moses and Knutsen (2012, *pp.* 3–5) observe that this distinction is often lost and that the terms are frequently used as synonyms, with methodology used as a fancy version of methods. They agree with the viewpoint that the term 'methodology' refers to strategic level thinking and quote Waltz (1979, p. 13) who says "*once a methodology is adopted, the choice of methods becomes merely a tactical matter*". In essence, a methodology is the philosophical basis upon which methods lie.

A cursory examination of published works (especially textbooks) on methodologies might lead one to believe that the big methodological divide is that between quantitative methods and qualitative methods (Crotty, 1998, p. 14). However, such an emphasis on procedures and techniques hides the importance of establishing the conceptual and theoretical framework of research prior to, and as a necessary precursor to, considering particular methods.

While it may be argued by some that in the natural (or physical) sciences that questions relating to the nature of reality and how knowledge about this reality can be discovered have largely been settled[16] (although this is disputable) – this is most definitely not the case

[15] Fellows and Liu (2008, p. 67) observe 'Many people are prone to use the term methodology as equivalent to the scientific empirical approach'
[16] Although, it could also be argued that the philosophy of (natural) science is not as settled as assumed, given the nature of quantum theory, in particular Heisenberg's uncertainty principle and

with the study of social phenomena. This stems to a large degree from the nature of social entities, as Giddens (1984, *pp.* 348–349) points out, the natural sciences stand apart from what they study, whereas the social sciences are "*involved in a subject-subject relation with what they are about*". The fact that human beings are themselves knowledgeable adds complexity to any attempt at knowledge discovery in the social world[17].

In this chapter the research process and in component parts shall be explored in detail, with the objective of – to paraphrase Moses and Knutsen (2012, p. 5) – investigating the concepts, theories and basic principles and reasoning underlying the research presented in this thesis *i.e.*, exploring the philosophy of knowledge and explaining the paradigm (Kuhn, 1996, p. 10–11; original 1962) or world view (Creswell, 2014, *pp.* 5–6), upon which the research is based.

2.2 Research process

Research (especially but not only while researching social phenomena) is often described as a journey or a process wherein a search for knowledge is undertaken and eventually one arrives at a destination, where more is known about the phenomena of interest (Lampard & Pole, 2002, p. 2; B. Matthews & Ross, 2010, p. 7). There are a variety of ways of looking at this process. Denzin and Lincoln (2005a, *pp.* 21–26) see the (social) research process as being composed of five phases as shown in Figure 3 below.

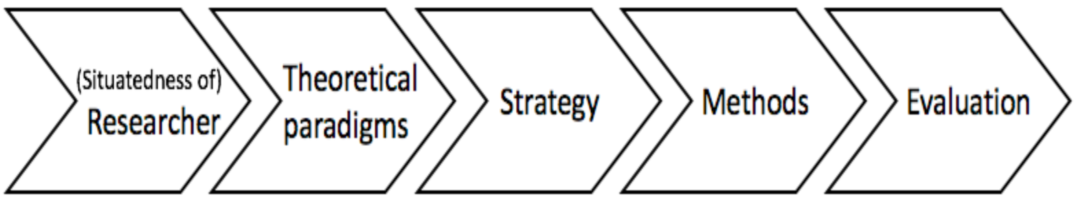


Figure 3: Five phases of research process *(after Denzin & Lincoln, 2005a, p. 25, table 1.1)*

chaos theory (see *e.g.,* Campbell, 1998; S. M. Rosen, 2015). Such explorations while most interesting, however are not germane to the work of this thesis.

[17] For example, both the natural sciences and the social sciences have potential to transform practice – however the key difference as Taylor (1983, p. 74 quoted in Giddens, 1984) observes is that the practice natural science might transform is not what the theory is about whereas the practice social sciences potentially transforms "*is the object of the theory*".

- The first phase deals with the role of the researcher and their 'situatedness' – both in terms of research traditions, and within the research process itself;
- Phase two considers the philosophical and theoretical perspectives, which underpin the research;
- The third phase addresses research strategy *i.e.,* the "*bundle of skills, assumptions, and practices that the researcher employs*";
- Phase four deals with methods for data collection and analysis;
- Phase five addresses what they refer to as "*the art, practices and politics of interpretation and evaluation*".

Saunders *et al.* (2009, p. 108) forward a different perspective on the research process with their so-called research 'onion' (see Figure 4 below) in which they attempt to illustrate the key components (and the associated choices) of research.

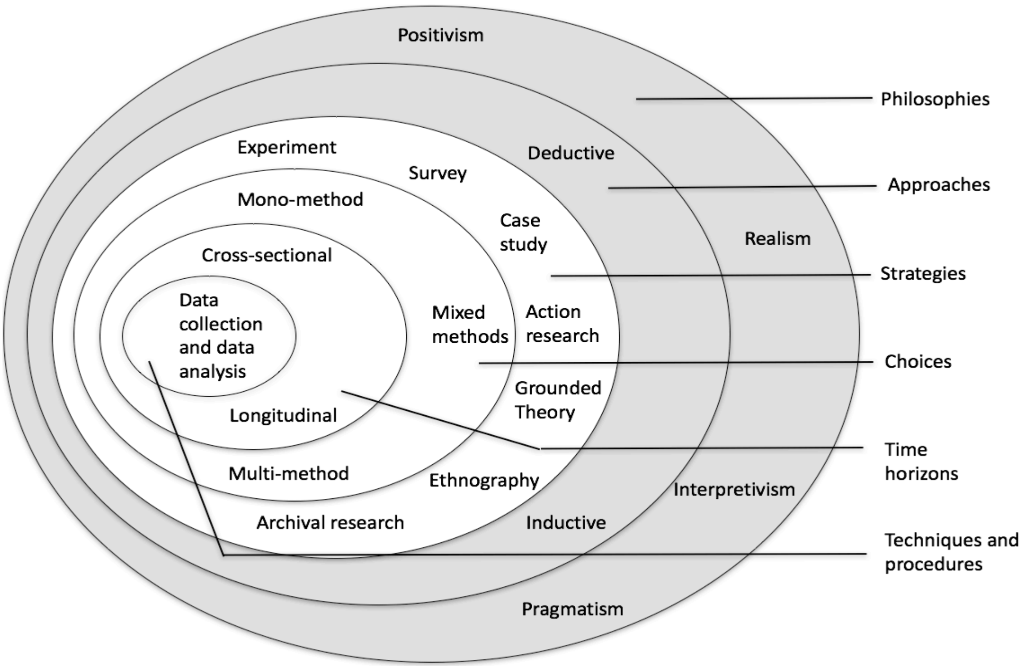


Figure 4: Research 'onion' representation of research process *(after Saunders et al., 2009, p. 108)*

While this is quite a different representation of the research process it can be seen that the 'onion' and the 'five phases' have a lot in common. The outer two layers of the research onion deal with research philosophies and approaches (*e.g.*, ways of seeing the world, theories on the nature of knowledge and on how knowledge can be best obtained). These can be considered as corresponding to the first two of Denzin and Lincoln's 'five phases' (albeit the researcher phase is taken for granted and to a great extent subsumed within the philosophies segment). The next three segments: strategies, choices and time horizons can be mapped to the strategy phase, while data collection and data analysis can be equated with the methods and evaluation phases.

Easterby-Smith *et al.* (2012, *pp.* xiv–xvi) forward another perspective using a tree as a metaphor for the research process, with a cross-section of the 'trunk', as shown in Figure 5 below, symbolising the main features of research design, namely:

- Ontology *i.e.,* view of the nature of reality;
- Epistemology *i.e.,* assumptions on the best means of inquiring about the world;
- Methodology *i.e.,* ways in which methods are grouped to provide a coherent approach;
- Methods and techniques for date collection and analysis.

This perspective places elements of research philosophy (ontology and epistemology) at the core and signifies the fundamental influence of the research philosophy adopted on the methodological choices, which in turn influences the selection of methods and techniques.

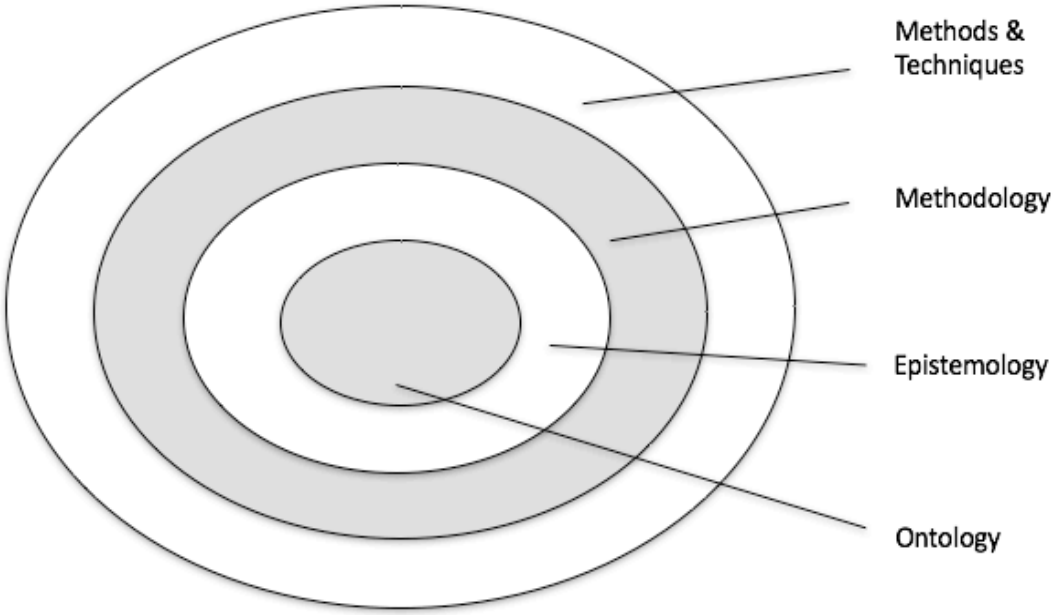


Figure 5: Research 'tree trunk' (after Easterby-Smith *et al.,* 2012, p. xv)

There is an tendency to associate specific methodologies and methods with particular philosophical stances[18,19] – even though they may have application value across a range of philosophical stances (Saunders *et al.*, 2009, p. 106). The positioning of philosophy in the research 'onion' (Figure 4 on page 36) risks giving the impression that research philosophy is 'wrapped around' methodologies and methods, which may imply an overly restrictive menu of options available. However, Johnston (2014) observes that this is not necessarily an issue as both the Saunders *et al.* 'onion' and the Easterby-Smith *et al.* 'tree trunk' models "*highlight the importance of ontology and epistemology as starting points of the research process*" and posits that whether a researcher working out from the core or in from the surface is inconsequential as the significance of the models lie in the importance placed "*on ensuring a focussed and consistent background to the process"*. While this view has merit, care must be taken that following a particular research process model does not result in the presumption of unnecessary restrictions on method selection.

[18] These philosophical stances are described later in this chapter.
[19] The classic examples being: qualitative research associated with constructionism (*e.g.,* Boeije, 2009), and quantitative research associated with positivism (*e.g.*, Pollack, 2007).

2.3 Researcher positionality

As Denzin and Lincoln (2005a, *pp.* 21–22) observe, the researcher occupies a central role in the research of social phenomena both in terms of research traditions, and within the research itself. Merriam (2009, p. 160) observes that within qualitative research the researcher is the primary instrument of data gathering and analysis. While this can be advantageous providing responsiveness and adaptability, being such an integral part of the process means that the researcher inherently brings bias to the research; the key thing therefore is to make this explicit by identifying possible biases and acknowledging potential impact on research. Creswell (2007, p. 38) also sees the researcher as a key instrument of (qualitative) research, noting they tend to design and use the research instruments of the study, deciding: what is to be studied *i.e.*, the research question; which data is to be gathered and how, *i.e.*, data collection; how data is analysed; and how results will be interpreted. While some may attempt to disregard[20] or minimise[21] the potential effects of the researcher, for most researchers of social phenomena awareness of, and appreciation of, the biographically situated researcher is seen as an essential component of research study design (Denzin & Lincoln, 2005a, *pp.* 21–22; Wellington & Szczerbinski, 2007, *pp.* 51–55). Accordingly, it is best practice for the qualitative researcher to acknowledge their background[22] and to recognise and explicitly disclose their values, biases, assumptions that could shape and influence interpretations formed in the conduct of their research. Accordingly, the following few paragraphs comprise a reflection of the author's positionality with regard to the research presented in this thesis.

I, the researcher, have been researching the sustainability of socio-technical systems since I joined the Cleaner Production Promotion Unit, School of Engineering, University College Cork as a researcher in 2001. While, much of this work was initially concerned with

[20] Often using the rationalisation of objectivity.
[21] Through joining and adopting the norms of the group of interest – including as Wellington and Szczerbinski (2007, p. 51), note extreme examples of so-called 'covert research' where researcher join groups (*e.g.,* British army groups in Northern Ireland) for study purposes without their knowledge.
[22] This background also includes wider social context such as societal values, language, culture, *etc.*

sustainable production and consumption topics, the human dimension was always prominent.[23] The importance of this aspect in my work grew as human and societal aspects in sustainability were increasingly recognised as legitimate by research collaborators, funding agencies, and client organisations. Thus, my background is one where the social aspects of sustainability are accepted as just as 'valid' and just as important as technological aspects. Furthermore, I acknowledge and appreciate that such social dimensions cannot be treated simply as another variable in research but requires specific research approaches to develop an understanding.

By definition, I was an 'outsider' to the various organisations from which respondents for the research were drawn. This meant that I came to the research with fewer preconceptions and perhaps more open to 'listening' than would have been the case had I belonged to those organisations. On the other hand, I was also cognisant that this also meant that I may have lacked context for some of what was been reported. However, because both I and the respondents were also aware of this outsider status, assumptions were explained and explored (with prompting where necessary) that may have been taken for granted with someone from within their organisation.

My academic background is a combination of the natural sciences and political science, and I have been exposed to both quantitative and qualitative methods, and have routinely used both types of research approaches – either individually or in combination – throughout my research career. I am therefore not predisposed to one approach or another, but would see value in both, and choose the most appropriate method on the basis of research need.

2.4 Theoretical paradigms and perspectives

Quantitative methods are fundamental to modern scientific enquiry and may be considered

[23] Indeed this consideration of human (and societal) dimensions in addition to technical aspects is a key attribute of the research group from its establishment, as indicated by the choice of term 'cleaner production' in its name in place of the principal alternative term 'clean technology', which is almost exclusively concerned with technical solutions.

the bedrock of the natural sciences. A measurement of the flow of physical inputs and services within a value chain can be achieved through a Filière analysis (Bernstein, 1996; Raikes, Frilis-Jensen, & Ponte, 2000) or other quantitative value flow analyses, which would provide a certain understanding of the technical relationships between the component actors. However, to understand the interactions within the value chain, taking into account the human dimension in decision making, it is necessary to use approaches other than just the collection and analysis of numerical data and this necessitates qualitative techniques.

Qualitative analysis seeks answers to the questions as to how and why something occurs; typically explained in contrast to quantitative analysis, it enquires into what happened, where and when. In quantitative analysis proposed explanations (hypotheses) are deduced from preliminary literature research using preselected theory. The hypotheses are then proved or disproved by testing: comprising the collection of large standardised datasets, on which statistical analysis is conducted to determine if the hypotheses are supported. Findings are subsequently assessed in the context of the theory, and the implications drawn (Boeije, 2009).

According to Denzin and Lincoln (2005a, p. 10) the term 'qualitative' suggests an emphasis on the "*qualities of entities and on processes and meanings"* that are not derived from experimentation or quantifiable measurement. In qualitative studies, the subjects' actual deeds, words, gestures and other social interactions are the raw material for the analysis. Lindlof (1995, *pp.* 18–22) describes the objective of qualitative research as preserving the "*form and content of human behaviour and to analyze its qualities, rather than subject it to mathematical or other formal transformations*". A comparison between the objectives of quantitative and qualitative research is presented as Table 2 below.

Table 2: Research objectives (adapted from Franklin, 2013, p. 11, Table 1.1)

	Analysis and interpretation	
	Mode	**Objective**
Qualitative researchers	Deconstruct Generalise Infer (Re)assemble	Critique Describe Discover Empower Expand Explain Improve Nuance Recommend
Quantitative researchers	Deduce Generalise Infer Test hypotheses Validate	Describe Discover Explain Focus Improve Make casual inferences Refine Replace Predict Recommend Understand

Qualitative research is a situated activity comprised of a collection of research practices conducted by a researcher located in the world (or 'a world') to make aspects of the world more visible (Denzin & Lincoln, 2005a, p. 3). As Snape and Spencer (2003, p. 1) observe there is no single, accepted way of doing qualitative research. Morgan and Smircich (1980, *pp.* 491–492) posit that research is inherently based upon assumptions: ontological assumptions, on the nature of reality – what is the nature of what is being studied; epistemological assumptions, on the nature of knowledge – what and how can we know about the world? what is the relationship between researcher and reality?; and methodological assumptions, that inform the framing and approach to gaining knowledge on a subject. The set of assumptions adopted by a researcher – whether explicitly or by default – establish a paradigm under which the research will be conducted. This trio of philosophical orientations: ontology, epistemology, and methodology – dubbed by Moses and Knutsen (2012, p. 4) as *"the three musketeers"*, are fundamental to research design in the study of the social world.

Crotty's (1998, *pp.* 10–12) view that ontological and epistemological issues tend to emerge together is persuasive. His comment that this has often led to difficulties keeping ontology and epistemology concepts separate also holds a measure of truth (and is corroborated by Hammond and Wellington's (2013, p. 115) observation that it is very difficult to talk about one without the other). Furthermore, Crotty's (1998, p. 11) critique of the misuse of the term ontology by certain researchers is not without some validity. Notwithstanding these concerns, establishing the ontological assumptions being taken, is a necessary initial step in developing research methodology, lest it run the risk of incoherency (M. Hammond & Wellington, 2013, p. 115).

Ontology, as described previously, is the study of the nature of being, the nature of reality; in social science research it refers to the "*nature and reality of the social phenomena that make up the social world*" (B. Matthews & Ross, 2010, p. 478). Hammond and Wellington (2013, *pp.* 114–115) comment that this social reality is often seen in terms of a dichotomy between an objectivist ontology (also referred to as realist or foundationalist) which holds that an objective reality exists independently of the observer on one hand, and an anti-foundationalist ontology which sees social reality as being negotiated within groups (or perhaps less commonly, as being subjective to the observer) on the other.

Schmidt (2001, p. 136) considers **epistemology** to be a normative discipline, whose principle objective is to set the standards for how human science and reason should work rather than to accurately depict how they work in function. Even if this view was to be accepted, it does not lessen the importance of establishing a research study's philosophical orientation on how knowledge can be discovered (even if it is to be seen as a conceptual ideal rather than a real-life depiction). Positivist epistemology (also known as naturalism or empiricism), stems from an objectivist ontology and holds that the world we observe is 'real' and 'separate' *i.e.*, it exists independent of our senses and it is capable of being objectively described and interpreted (M. Hammond & Wellington, 2013, p. 120; Moses & Knutsen, 2012, p. 29). An additional implicit belief of positivists is that this reality is experienced and can be shared in the same way by everyone (Campbell, 1998). Moses & Knutsen (2012, p. 19) trace the origins of this naturalist tradition of enquiry to Galileo's publication of The Starry Messenger in 1610, which is *"often seen as the first true application of the scientific method"*. Natural scientists generally share this positivist stance seeing the world as based on fixed facts, ordered with certain discernible laws. The scientific method is seen as paradigmatic of the objective method (Audi, 1998, p. 263) and its hegemony in these research fields means that it is seen by some as the only legitimate means of research.

In the human and social sciences, there is no such epistemological hegemony. While many social scientists[24] hold that the positivist stance can be applied to the study of the study of the social world – many more see the social world as lacking the inherent order implicit in such a view. Positivist social scientists hold that there is a social reality to be observed and that it can be considered independently of both the researcher and research subjects (B. Matthews & Ross, 2010, p. 27). Charmaz (2003, *pp.* 83–84) observes that the aim of such approaches is to reduce *"qualities of human experience to quantifiable variables"*. In contrast, constructivism (interpretivism) sees the world very much, in an anti-foundationalist perspective, as a social construction, which needs to be interpreted. Moses and Knutsen (2012, p. 169) observe that while both positivists and constructivists see patterns in the world and agree on the need to explain them, they do so from very different perspectives on the source of such patterns – with positivism seeing such patterns as an

[24] There is of course much variation between the various disciplines and between different traditions within disciplines.

integral part of the observed world – in other words nature, while constructivism hold that the patterns originate in the mind that observes them *i.e.*, reality is subjective and experiential. There have been attempts to bridge the gap between positivism and constructivism, the most significant of which have been so-called realist approaches which combine aspects of positivism and constructivism of which there are a number of variations (Campbell, 1998)[25]. The realist epistemologies such as scientific realism or critical realism[26] are seen as straddling the positivist and constructivist perspectives, in a way that Moses and Knutsen (2012, p. 12) consider as offering promise, although they note it has yet to make much impact in the everyday study of the social world. Critical realism holds a 'realist' stance in which a social world is seen to exist and act independently of human experience, but also accepts that it is complex and that there may be many layers of meaning – as complexity of a social entity increases, the scientific realist viewpoint can be thought of as moving closer to constructivism, albeit with a realist perspective firmly at its core (Moses & Knutsen, 2012).

While Moses and Knutsen (2012, p. 14) admire critical realists' pluralist perspective on methods and their implicit rejection of the 'method cookbook' mentality, they remain cautious on the ambition of some realists to create a new unifying methodological tradition, which can not only straddle positivist and constructivist positions but also the physical and social sciences – instead they call for a methodological pluralism *i.e.*, choice of the conceptual framework to best meet research needs rather than a striving to create a one-size fits all. Moses and Knutsen (2012, p. 7) see positivism and constructivism as the predominant methodological traditions in the social sciences. Although viewing them as binary is rather a simplification, heuristically they are often presented as oppositional and in this context, Moses and Knutsen suggest that is may be best to consider them as points

[25] Variations such as scientific realism, critical realism, modest realism, naive realism, objective realism, strong realism, weak realism

[26] Interestingly, Moses and Knutsen (2012, p. 12) consider the scientific realism and critical realism to be interchangeable labels, whereas others, Sarantakos (2005, *pp.* 32–33) for example, would contend they describe different, albeit related concepts.

on a continuum, with most researchers finding themselves somewhere in between – obviously being closer to one pole or the other depending of the researches' (and researcher's) basic orientation. This continuum perspective perhaps goes somewhat to answering Schmidt's (2001) criticism of epistemology: that it is a normative discipline – the prospect of mapping epistemic approaches to such a continuum makes real life depiction more achievable. For the majority of social inquiry the choice of epistemological understandings lies between positivism and constructivism (M. Hammond & Wellington, 2013, p. 15), with critical realism seen either as a hybrid form or positioned in the middle of an epistemic continuum depending on one's perspective.

Table 3: Basic beliefs of alternative inquiry paradigms (derived from Guba & Lincoln, 2005, *pp.* 193–194 Tables 8.1 & 8.2)

	Positivism	**Postpostivism**	**Critical theory *et al.***	**Constructivism**
Ontology	Naïve realism – 'real' reality but apprehendible	Critical realism – 'real' reality and probabilistically apprehendible	Historical realism – virtual reality shaped by social, political, cultural, economic, ethnic, and gender values, crystallized over time	Relativism – local and specific constructed and co-constructed realities
Epistemology	Dualist/ objectivist; findings true	Modified dualist/ objectivist; critical traditional/ community; findings probably true	Transactional/ subjectivist; value mediated findings	Transactional/ subjectivist; created findings
Methodology	Experimental/ manipulative; verification of hypotheses; chiefly quantitative methods	Modified experimental/ manipulative; critical multiplism; falsification of hypotheses; may include qualitative methods	Dialogic/ dialectical	Hermeneutical/ dialectical
Aim of Inquiry	Explanation: prediction and control		Critique and transformation; restitution and emancipation	Understanding; reconstruction

	Positivism	Postpostivism	Critical theory *et al.*	Constructivism
Nature of Knowledge	Verified hypotheses established as facts or laws	Non-falsified hypotheses that are probable facts or laws	Structural/ historical insights	Individual or collective reconstructions coalescing around consensus

This choice of epistemic orientation has a significant bearing on the research approach as shown in Table 3 above. Positivistic approaches assuming an independent objective external world separate from unbiased and passive inquirers and the knowledge they accumulate (Charmaz, 2003, *pp.* 83–84), lead to methods which seek to explain the world through objective value-free techniques *i.e.*, hypothesis verification by means of *e.g.*, measuring physical attributes with mathematical analysis of resultant quantitative data. In contrast, constructivistic approaches assuming a socially constructed world in which inquirers themselves have an impact, lead to methods which seek to understand the world though value-aware techniques *i.e.*, theory building by means of *e.g.*, in-depth interviews with thematic analysis of resultant transcripts.

The research reported in this thesis holds that understanding participant interactions and the flow of (various) values within temporary multi-firm configurations requires a socio-constructivist approach (Berger & Luckmann, 1966). These interactions cannot be understood objectively, as there is no 'one truth' to be uncovered, each participant will have a different understanding of the truth — in keeping with Haraway's (1988) proposition that knowledge is partial and linked to the contexts in which it is created. Nor can be they be subjectively understood, as it is the participants' social interactions themselves that fundamentally create the collaborative structure and their perspectives that define the 'values' exchanged between them.

These multi-firm configurations are by their very nature social entities[27]. It should therefore

[27] While contractual and regulatory requirements will no doubt shape and influence the relationships within the configurations, they do not negate the inherent social nature of such relationships.

come as no surprise that this thesis, which aims to understand the workings of these inter-firm collaborations, takes an anti-foundationalist ontology and adopts a constructivist epistemology.

2.5 Research strategies

2.5.1 Approaches for data collection and analysis

Qualitative analysis aims to understand the social dimension of an issue through deeper engagement with smaller samples. Hypotheses are not forwarded in advance, to be tested against the data, but rather findings are expected to emerge from the collected data during the research process. This means the principled development of the research strategy (and indeed research instruments) to suit the scenario being studied as it is revealed, as opposed to the disciplined application of established rules within quantitative studies. Within qualitative studies, subjects of interest are explored, themes emerge from the data and this in turn facilitates more informative explorations of the subjects. Through an iterative process a theory is constructed from the data based from the emergent themes (Holliday, 2002, *pp.* 1–7).

Denzin and Lincoln (2005b, p. 379) define a strategy of inquiry as an approach describing the "*skills, assumptions, enactments and material practices*" researchers use as they translate a research paradigm into data collection (and analysis). The social sciences, in which qualitative methods originated, have put forward a plethora of methods and techniques designed for different contexts and use-cases. There are thus a number of different traditions of approaches to qualitative data collection and analysis, including for example:

- Discourse Analysis – studying and analysing the use of language in a variety of ways, *viz.*, formal linguistic discourse analysis (*e.g.,* see Lacson, Barzilay, & Long, 2006); empirical discourse analysis (*e.g.,* see Ford-Summer, 2006); and critical discourse analysis (*e.g.*, see Foucault, 1972);

- Ethnography – involves studies of a culture or a group (team, organisation *etc.*) with a shared culture through participant observation: exploring and documenting the interactions, behaviours, and perceptions that occur (*e.g.,* see S. Reeves, Kuper, & Hodges, 2008);

- Grounded Theory Analysis – involves the systematic development of theory grounded or based in the collected qualitative data that have been iteratively categorised and re-categorised as themes and potential theories emerge (see Glaser & Strauss, 1967);

- Narrative Analysis – aimed at understanding a series of events, the focus is placed on how the informant puts order on the events in which they have participated (Schutt, 2012, *pp.* 339–341);

- Phenomenology – considers features of the world according to their appearance to an inquiring consciousness "*… through interrogation of the languages of experience – including pictorial, psychological, and political, as well as verbal, languages*" (Silverman, 1980, p. 709);

- Generic qualitative methods – these are broad based approaches that aim to select the best solution on a case-by-case basis which regard to the nature and context of the intended study. Generic qualitative research can thus be defined "*as that which is not guided by an explicit or established set of philosophic assumptions in the form of one of the known qualitative methodologies"* (Caelli, Ray, & Mill, 2003).

2.5.2 Selecting an approach

Alternative approaches could be used for the type of research explored in this thesis, for example there have been a number of studies where ethnographic approaches have been taken to research on behaviour and interactions within specific businesses (*e.g.*, Baird, Moore, & Jagodzinski, 2000 in Rolls Royce Aerospace; Corbitt, 2000 within a large financial institution; or Myers & Young, 1997 within a New Zealand Crown health enterprise).

However, ethnography is focused on exploring culture within groups and would be less useful for exploring the nature of the temporary multi-firm configurations that deliver building renovations – especially as in many cases, many organisations may not even recognise that they are in fact a member of such configurations.

Another candidate approach would be grounded theory, considered particularly appropriate for discovery-oriented research in under-theorised areas (Burck, 2005, p. 224). As would be the case with the actor interactions within building energy efficiency marketplace. Lingard *et al.* (2008) identify three key inter-linked features of grounded theory research, *viz.*, iterative study design, with cycles of simultaneous data collection and analysis informed by previous cycles; purposive sampling, with data analysis influencing selection of subsequent informants; and data analysis involving constant comparison as concepts and themes emerge. However, Grounded Theory's focus on constructing theories as opposed to appreciating perspectives and understanding phenomena reduce its usefulness for this type of research.

This thesis seeks to discover and understand the actor interactions within those *ad hoc* virtual organisations that deliver building energy renovations. The stakeholder engagement approach, which forms the basis of this thesis owes a great deal to principles of grounded theory, particularly in relation to the methods employed in the collection and analysis of data, and the concept of findings emerging from the data as opposed to conducting data analysis to test hypotheses. This tallies with Burck's (2005) view that the Grounded Theory approach has had *"… a huge impact on qualitative research interviewing"* and that its recursive and iterative nature fits well with the practicalities of field research.

The methodological legacy is therefore unmistakeable and so it may be regarded as a Grounded Theory informed methodology. This is especially so in the context of Strauss' (1987) view of Grounded Theory as a style of doing qualitative analysis rather than a specific approach. However, in so far as the methodology was not designed to completely adhere to the norms of Grounded Theory or any other established qualitative methodology, it can be considered a generic qualitative methodology[28]. Merriam (1998, p. 11 quoted in Caelli *et al.* 2003) posits generic qualitative research studies as those that exemplify the characteristics of qualitative research in that *"… seek to discover and understand a phenomenon, a process, or the perspectives and worldviews of the people involved*". This is exactly what this research aims to achieve.

2.6 Methods of collection and analysis

2.6.1 Setting the scene

Before selecting methods, it is useful to consider the objectives of the study. Ritchie (2003, p. 27) avers that qualitative research has a number of functions, including:

- *Contextual* – describing the nature of what exists;
- *Explanatory* – determining the reasons for what exists;
- *Evaluative* – evaluating the effectiveness of what exists;
- *Generative* – creating ideas for what might exist (developing theories).

Each of these classifications relates to the social context *i.e.*, social phenomena. The function of any specific qualitative research determines the type of evidence that is required. To work towards these objectives, there are a variety of qualitative methods for data collection and analysis, for example: observation; textual and visual analysis; individual and group interviews; *etc.* (Gill, Stewart, Treasure, & Chadwick, 2008, p. 281). The research within this project may be considered to be both explanatory — in that it aims to explain the make-up of the temporary multi-firm configurations, and contextual — in that it seeks to describe the workings of such groupings.

[28] However, as Ormston, Spencer, Barnard, & Snape (2014, p. 21) argue, and as illustrated by the discussion elsewhere in this chapter, adopting a generic qualitative methodology does not necessarily imply a lack of theoretical and philosophical basis to the research design.

Perry (2011, *pp.* 75–114) holds the view that research can be classified into three intersecting continua *viz.*, exploratory – confirmatory (from exploring something new to confirming existing theories); qualitative – quantitative (information on the 'qualities' of entities, meanings and process to measureable quantifiable data); basic – applied (highly theoretical to the very practical). Figure 6 illustrates the research presented in this thesis mapped onto Perry's axes of research classification.

Firstly, developing an understanding of the workings of the *ad hoc* businesses groupings that deliver building energy renovations is obviously more exploratory than confirmatory. Secondly, the rich 'thick' data collection required to explore this topic, and understand the participants' stories, required qualitative enquiry. Thirdly, with the objective of supporting renovation project delivery configuration for satisficing participants; the project is definitely in the applied camp. Thus, the research can be said to be qualitative, exploratory, and applied and shown by the blue 'X' on Figure 6 below.

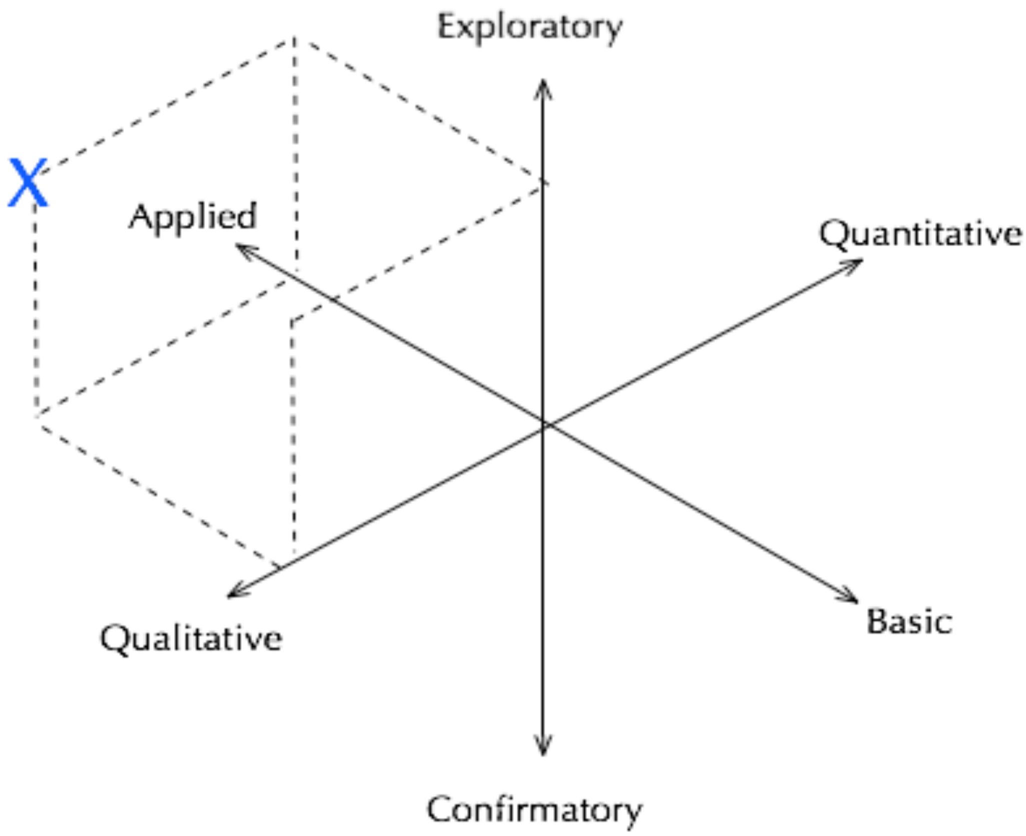


Figure 6: Research design classification on axes of research classification (after Perry, 2011, *pp.* 76, 86)

2.6.2 Review of literature

A critical part of any research study is a review of literature relevant to the topic at hand. Ryan (2006, p. 58) says the aim of such review are to explore what is known about a topic and to introduce the main authors in an area – in effect setting the scene for the research.

Schwandt (2007, p. 266) notes that literature reviews involve the comprehension, analysis and synthesis of multiple studies with a view to solve a problem, understand an issue, explain a relationship, *etc.* Literature reviews are often considered almost a precursor to 'actual' research, while in fact they are an integral and a crucial part of the research process. Moreover, a review of literature can in and of itself constitute a worthwhile research method leading to new knowledge and insights (Torraco, 2005).

Fink (2010, p. 5) identifies seven tasks involved in reviewing literature, namely: (i) selecting research question; (ii) selecting bibliographic databases and other sources of literature; (iii) choosing search terms and combinations of terms; (iv) applying practical screening criteria *e.g.*, language, availability; (v) applying methodical screening criteria *e.g.*, methodological approach; (vi) 'doing' the review; and (vii) synthesising the results.

All chapters in this thesis include some review of literature, however the principal review of literature is divided into two parts: with Chapter 3 addressing buildings and their energy consumption, and Chapter 4 exploring value creation and business models. The aforementioned seven tasks will be explored in more detail in these chapters.

2.6.3 Interviews

Interviews are a commonly used research tool to capture experiences and ascertain the attitudes, perceptions and inner feelings of informants. Wimpenny and Gass (2000, p. 1491) note that phenomenological studies often rely on (in-depth) interviews as the sole means of data collection, while grounded theory approaches may have many different data collection methods. Gill, Stewart, Treasure and Chadwick (2008, p. 281) observe that fundamentally there are three types of interviews: unstructured, structured and semi-structured.

- Unstructured interviews are those in which neither the question nor answer categories are predetermined. They will commence with an open-ended inviting question and subsequent questions will follow from the responses given;

- Semi-structured interviews comprise a number of key questions; allowing the topic of the interview to be defined, while still allowing the areas of particular interest (to either the interviewer or interviewee) to be explored in more detail;

- Structured interviews are characterised by predetermined questions and are essentially verbally administered questionnaires, with no scope for follow on questions on responses that may be of interest.

In practice, interviews can be said to form a continuum, Newton (2010), describes the unstructured pole of this continuum as being closer to observation, with the structured pole closer to forms of questionnaires.

The in-depth semi-structured interview was chosen as the primary instrument for gathering the information in this research. Bryman and Bell (2011, p. 472) make the point that semi-structured interviews are appropriate where the research has a focus; furthermore, Longhurst (2009, p. 282) observes that in comparison with semi-structured interviews that other *"... methods such as observation, closed questionnaires, census data and structured interviews do not allow for much discovery or probing"*. Thus, the semi-structured interview was seen as offering the most effective means of capturing opinions, experiences and interpreting behaviours so as to better understand the interactions of actors within the value chains associated with building energy efficiency projects.

Semi-structured interviews set up a scenario in which an informant is provided with the time and scope to talk about their opinions on a particular subject. The objective is to understand the informant's point of view, rather than extrapolate findings to make generalisations. The interview is treated as a conversation and the researcher tries to build a rapport with the informant and questions are asked when the interviewer feels it is most appropriate to ask them *e.g.*, questions, which the informant can answer easily may be asked first to put them at ease (Gill *et al.*, 2008).

While an interview schedule, comprising a list of questions of topics to be covered, is prepared in advance of the interview to guide the conversation to those areas most relevant to the research at hand, informants will have sufficient scope to fashion their responses to include issues they feel are relevant. Questions may not be asked exactly in the same order or in the precise language contained in the schedule, but generally all questions will be addressed and put to the informants in similar manner. If deemed necessary informants may be asked additional questions for clarification and to explore new points of interest as they arise (Bryman & Bell, 2011, p. 467). The actual method for the conduct of the interviews for this research study will be described in more detailed in Chapter 5.

2.6.4 Analysis of interview transcripts

Schwandt (2007, p. 6) describes the analysis of qualitative data (such as interview transcripts) as making sense of, interpreting, and theorising data through a variety of methods that involve working iteratively back and forth between data and ideas. In analysis of qualitative data, analytical categories are used to describe, characterise and explain social phenomena (Pope, Ziebland, & Mays, 2000), this is achieved through a cursive, laborious, and time-consuming process.

Qualitative data such as interview transcripts are analysed by systematically ordering, categorising, through a process known as coding *i.e.*, applying a code "*most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data*" (Saldaña, 2013, p. 3).

There are a number of methods for analysing qualitative data including: the analysis methods associated with Grounded Theory (Glaser & Strauss, 1967) (*e.g.*, see Glaserian and Straussian views on analysis, and variants thereon[29]); conversation analysis (albeit with a focus on naturally ocurring conversations *e.g.*, see ten Have, 2007); discourse analysis (*e.g.*, see Dick, 2004); narrative inquiry (*e.g.*, see Riessman, 1993, *pp.* 54–63).

While, as acknowledged on page 50, the methodology adopted by this research has been informed by Grounded Theory (and specifically the Glaserian school), the analysis of the interview transcripts undertaken in this thesis did not follow the protocols typically associated with Grounded Theory approach(es) – particularly the concept of coming to the data completely free of preconceptions. Systematic analysis that does not follow one of these specified methods is referred to as thematic analysis (Schwandt, 2007, p. 291) or thematic content analysis (*e.g.*, see C. P. Smith, 1992). The analysis of the interview transcripts can be said to be conducted through a thematic analysis that had certain high-level objectives, but at the same time strived to be as grounded in the data as possible.

The interview transcripts were coded using template analysis, which as King (2004, p. 256) explains comprises not one but rather a group of techniques for organising and analysing data. This involved creating a list of codes – the 'template' – representing themes found in the text. Some codes were defined a priori, but were subsequently refined and developed in the course of coding the interview transcripts - *i.e.*, assigning codes to segments of text. As the coding process advanced, relationships between the codes became apparent, the template was thus structured in a hierarchical manner denoting such relationships.

Qualitative data analysis software (specifically NVivo as shown in Figure 7 below) was used in this analysis process. Such software does not automate the analysis but does facilitates coding, organising, linking and cross-referencing of material.

[29] Glaser (1992) sees *Grounded Theory* analysis as a purely inductive process where theories emerge from the data, while Strauss (1987, p. 12) considers that induction, deduction and verification are essential parts of *Grounded Theory* analysis (Stern, 1994, p. 220).

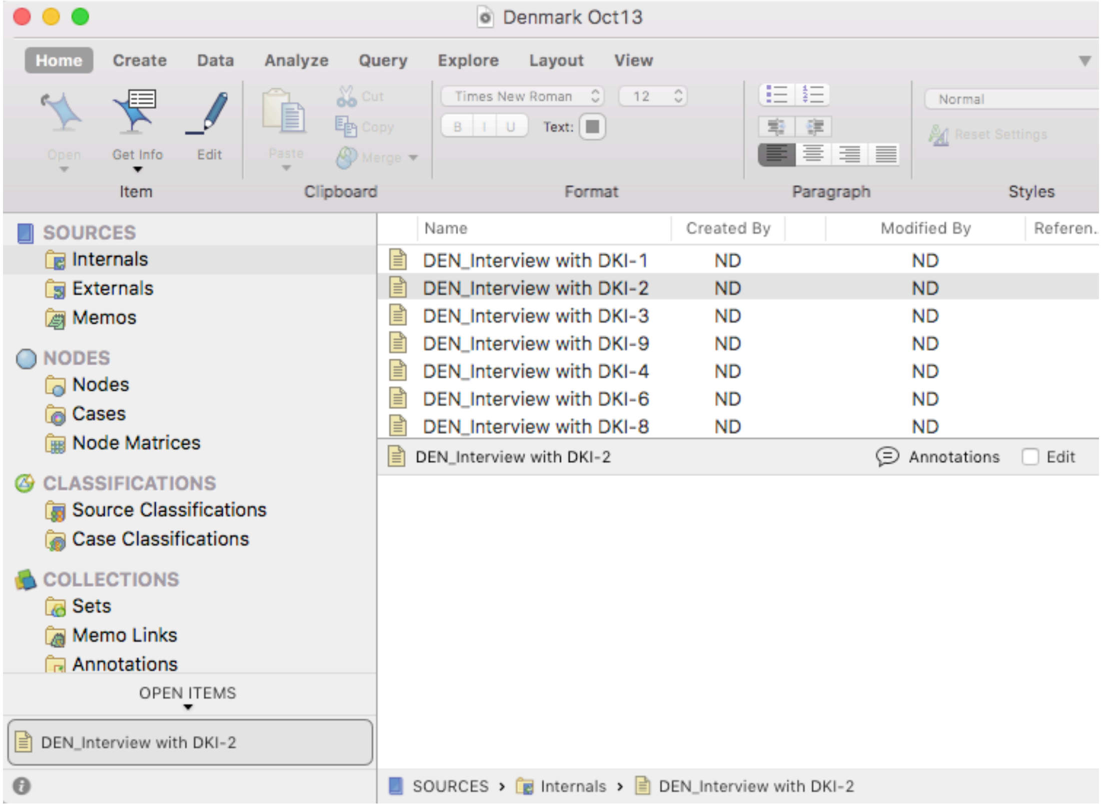


Figure 7: Screenshot of NVivo software

It may be considered, as such, a specialised database which helps in the organisation and supports the analysis of qualitative data. The actual data analysis method will be described in more detailed in Chapter 5.

2.7 Conclusion

The objective of this chapter was to consider the research process for this research presented in this thesis and in particular to investigate the concepts, theories and basic principles and reasoning underlying the research. The chapter aimed to explore the philosophy of knowledge and explain the paradigm upon which the research is based. The temporary multi-firm configurations, which deliver energy renovations are by their very nature, as groups of people, social entities. As noted on page 33, research which aims to understand social systems, such as those groups, requires the use of methodological understandings and approaches from the human and social sciences. The research presented in this thesis takes an anti-foundationalist ontology (holding that social reality does not have an objective existence, independent of the observer) and adopts a constructivist epistemology (seeing the social world as a construction, which needs to be interpreted). As mentioned on page 47, the research philosophy of this thesis holds that understanding participant interactions and the flow of the various values within the aforementioned multi-firm configurations cannot be objectively determined – rather the nature of the workings of these configurations is itself a social construction, that need to be interpreted. To deliver this required interpretation, the research approach adopted for this thesis is a generic qualitative methodology (albeit one informed by grounded theory), which uses literature review, in-depth face-to-face interviews and thematic analysis as its principal methods of data collection and analysis.

3 Buildings and energy – a review

"Ah, to build, to build! That is the noblest of all the arts" – Henry Wadsworth Longfellow

This chapter reviews the literature associated with buildings and energy. In keeping with the longevity of buildings and the nature of their use, the review takes a whole life or life cycle perspective on the built environment. Concepts and methodologies associated with consideration of the life cycle environmental aspects of buildings are reviewed, with a particular emphasis placed on energy consumption and associated emissions.

3.1 Introduction to the chapter

Buildings are long-life, fabricated (either onsite or off-site), structures with roof and walls, of various sizes and shapes, intended to serves the needs of humans. They are generally designed for a specific purpose, examples include houses, offices, factories, *etc.* Buildings consume a large amount of energy directly for heating and cooling, lighting, sanitation, ventilation, *etc.* and indirectly through the various energy consuming appliances they house. Moreover, a substantial amount of energy is consumed in the construction and renovation of buildings – so-called embodied energy. The significant energy consumption of buildings, coupled with their longevity (50- to 100-year life spans are not that uncommon) not to mention periodic renovations and perhaps repurposing over their life, means that the relationship of buildings with energy is a complex story. This review of literature attempts to tell this story: exploring the meaning of life cycle with respect to buildings; examining energy implications over the life of a building; reviewing a number of different life cycle performance metrics; and exploring how this may be relevant for this study. Section 3.2 details the method used in reviewing this literature.

3.2 Method for review of literature

As discussed in Section 2.6.2, review of literature is a critical part of the research process both in terms of 'setting the scene' for the research to be conducted *i.e.*, exploring existing knowledge, theories and practices in the relevant areas (Webster & Watson, 2002) but also (albeit not universally recognised[30]) as serving in its own right as a research method which can produce new knowledge and deliver new insights, for example through what Torraco (2005) refers to as an integrative literature review. This section uses Fink's (2010, p. 5) seven tasks[31], as a framing mechanism to describe the method used in reviewing the relevant literature for this chapter[32].

3.2.1 Which topic?

Fink's first task is the selection of the research question to orientate the review. In this research, the over-arching research question concerns ways of configuring building energy renovation project, such that all (key) participants are satisficed. While this is an extremely broad topic, it does serve as a starting point for consideration. Focusing on this topic, the initial question that presents itself is what is the nature of the relationship of buildings with energy over their lifespan? This chapter will review the literature that pertains to that question

3.2.2 Which literature sources?

The second task relates to the selection of bibliographic databases and other sources of literature. In addition to UCC library catalogue, the primary sources of literature used for this research were bibliographic databases which were either freely accessible or made available through university subscriptions. As the strengths of various database services differ, it is considered advisable to use a number, so as to overcome the weaknesses that may be associated with individual services (Falagas, Pitsouni, Malietzis, & Pappas, 2008). For the purposes of the research within this chapter, and indeed within this thesis as a

[30] For example, Onwuegbuzie and Freis (2016) observe a false impression held by some, and indeed even promulgated by a number of research methodology textbooks that a research literature is simply a preliminary task to be enduring and quickly got out of the way before the start of 'real' research.
[31] As outlined on page 34: (i) selecting research question; (ii) selecting bibliographic databases and other sources of literature; (iii) choosing search terms and combinations of terms; (iv) applying practical screening (v) applying methodical screening (vi) 'doing' the review; and (vii) synthesis.
[32] With similar approaches used in Chapter 4 and elsewhere in the thesis where literature was reviewed.

whole, the primary commercial databases utilised were: Science Direct, Web of Science, SCOPUS, and JSTOR. Google Scholar has been criticised for a number of reasons including inaccurate citations; inclusion of non-scholarly material; multiple versions of texts; unclear selection and ranking schemes; *etc.* (Falagas *et al.*, 2008; Jacsó, 2006, 2010). Notwithstanding these legitimate criticisms, Google Scholar was used to complement the other bibliographic databases, not least due to the power of its search algorithms, however it was used only as a supplementary source and in full knowledge of its shortcomings.

3.2.3 How to search?

The third task identified by Fink (2010, p. 5) is choosing search terms and combinations of terms. The databases were queried using Boolean keyword searches (*i.e.*, based on Boolean logic limited to two values: 0, 1; yes, no; *etc.*), where combinations of words and phrases using Boolean operators 'and', 'or', 'not' to search for relevant material. Such searches are flexible and allow for sophisticated searches. Examples of some initial search term combinations employed include: 'built environment' OR 'buildings' AND 'life cycle'; 'buildings' AND 'life cycle energy' OR 'whole life energy'; 'buildings' AND 'greenhouse gas' OR 'carbon footprint' OR 'whole life carbon'.

In addition to the databases searches described above, relevant literature which may have been missed through the search of the database were found through what might be termed a snowballing strategy comprising: 'backward snowballing', literature listed in bibliographies of papers identified through keyword searches; 'forward snowballing', literature that has cited the identified papers; and relationship 'snowballing', articles recommended by the bibliographic databases based on relevance scoring.

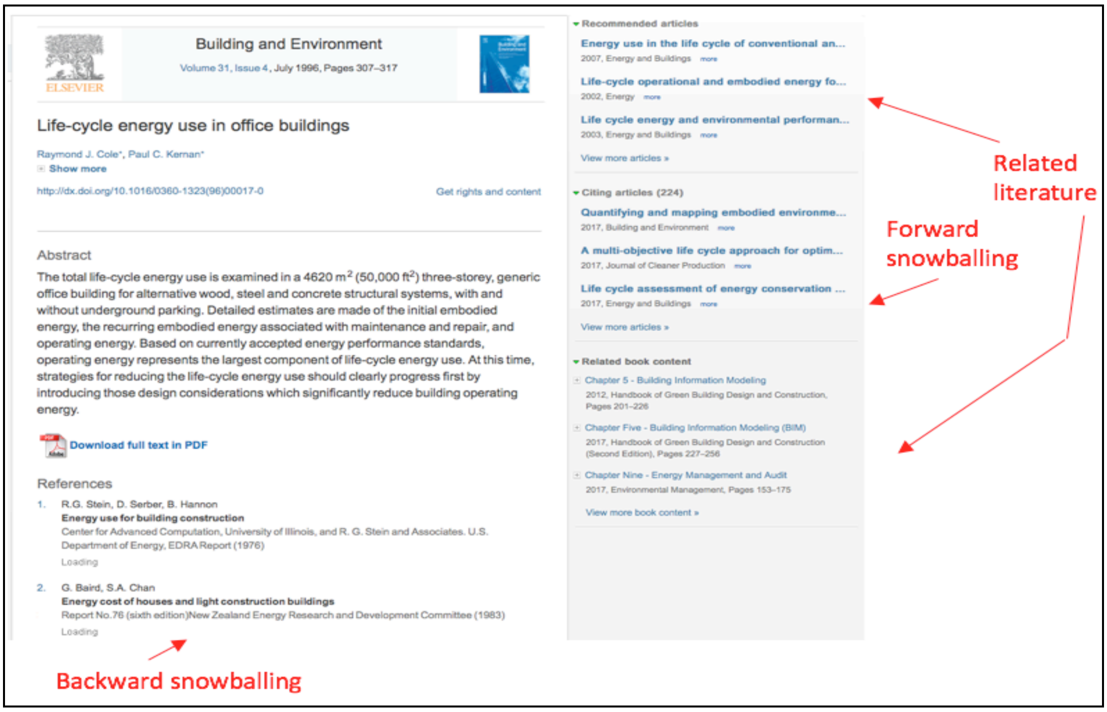


Figure 8: Illustration of how bibliographic databases assist in finding material

3.2.4 Screening

The next two steps involve applying screening criteria to reduce the amount of identified literature. Fink (2010, p. 59) argues that both practical and methodological screening are required to "*ensure the review's efficiency, relevance, and accuracy*". Firstly, practical screening criteria are applied to "*identify a broad range of articles that may be potentially usable in that they cover the topic of interest, are in a language you can read, and are in a publication you respect and can be obtained in a timely manner*" (2010, p. 59).

Whether acknowledged or not, a primary practical exclusion criterion in any literature review is language — if the researcher is unable to read the literature then it is of no practical use to them. However, such language limitations pose the risk of overlooking relevant and potentially important literature. In this regard those working in the English language are in a fortuitous position, as it is increasingly seen as the language of international communication. While there are risks in limiting literature searches by language, the status of English as the contemporary academic lingua franca, acts to minimise if not quite negate them. While 100 years ago "*French, English and German were all used for science and technology in international publication*" (Björkman, 2013, p. 8), this has changed completely and it can now be said that “*English is unquestionably the world language of academia*” (Mauranen, Hynninen, & Ranta, 2010, p. 183), or as Mortensen & Haberland (2012) call it: “*the new Latin*”. However, this perspective leads to what Lillis and Curry say “*might be referred to as an (invisible) English bias in academic literacies research*” (2010, p. 22). While one would have to sympathise with this view somewhat, the current status of English is such that if important literature is not published in the language[33], it will likely have been cited by somebody who did publish in English, and so would be found through backward snowballing as described above. For the small number of potentially relevant literature found in this way, a review of translations of abstracts indicated their value of otherwise.

A second practical selection criterion was the availability of the literature through the UCC library — this would mean there was no additional costs and that it was (generally) immediately available. Where a piece was not available locally, attempts were made to obtain through other sources – this included through institutional repositories, subject repositories, direct from the author *etc.* When a source was particularly relevant and proved unavailable through the university library or the alternative sources, the inter-library loan facility was utilised. However, there was both a financial and time cost in using this service, alternative means of access were exhausted first.

Following application of this practical screening, methodical screening criteria was applied to the residual documents, this focused on: the research methodological background; the apparent quality and rigour of the work (this involved assessing the quality of the work as presented and using proxies such as quality of journal or publishing house, institutional standing, quality of previous related work, author reputation, *etc.*)[34]. The outcome of this screening, which was an iterative process, was a pruning of the literature to a reasonable

[33] A review of the names in the bibliography of this thesis illustrates the wide range of nationalities cited in this thesis.
[34] It should be said that the use of quality proxies described above was not carried out in an overly formalised manner. Rather knowledge of the literature (which of course increased as the review progressed) was used to make assessments on a continuous basis.

amount – small enough that it was possible to review it and comprehensive enough that there were no glaring omissions.

3.2.5 Review and synthesising literature

Fink's Step 6 was the actual review of the selected and collected literature[35] and Step 7 synthesising the results. Webster and Watson (2002) quote Bem[36] saying: "*Authors of literature reviews are at risk for producing mind-numbing lists of citations and findings that resemble a phone book – impressive case, lots of numbers, but not much plot"*. The objective of this literature review is to explore the relationship of buildings with energy over their lifespan, producing a narrative that will be more than just descriptive *i.e.*, the aim is produce a review that will in the words of Jesson and Lacey (2006) be "*original, perceptive and analytical*".

Details of the collected literature were entered into reference management software[37], resulting in the creation of a library of references, which was extremely usable. The review of the documents themselves comprised an iterative process of search – read – annotate – organise – summarise – analyse – synthesise. The use of the aforementioned reference management software facilitated a more effective literature review, enabling efficient reading, notetaking and organisation of documents.

3.3 The 'life' of a building

3.3.1 Defining a building's life cycle

Buildings may be considered as products, albeit complex and long-life instances, and it is necessary to consider a building's life cycle from this perspective. All products and services can be thought of as having a 'life cycle', however the use of this term can be ambiguous, especially when used in interdisciplinary discourse (Guinée *et al.*, 2011). Hochschorner

[35] Of course, it should go without saying that the literature review steps were carried out iteratively.
[36] Bem, DJ, (1995). Writing a Review Article for Psychological Bulletin, *Psychological Bulletin* Vol. 118, No. 2, *pp.* 172-177
[37] Initially the software used was Papers app [http://papersa*pp*.com] however during the research this was change to Mendeley Desktop [https://www.mendeley.com] as this was increasingly the tool the author used professionally.

(2008), for example observes the differences in meaning when used in environmental and financial analyses. Differences in understandings of 'life cycle' have the potential to cause confusion in both the planning of a study and the communication of its results and therefore clarity is vital. This section will explore how in different contexts, different meanings may be attached to the term product 'life cycle', including:

Product (market) life cycle comprising the phases of a product within a market, as used in determining pricing strategies, typically presented as four phases, *viz.*, introduction, growth, maturity and decline (Dean, 1950; Vernon, 1966). Such a market-orientated perspective may not seem particularly relevant to buildings; however, it has direct applicability to the products that go into the construction or renovation of a building. Indeed, it is particularly relevant when considering novel products developed, for example, for building energy efficiency applications. It is interesting therefore to view this market-orientated product life cycle in conjunction with the technology life cycle (shown in lighter shade) in Figure 9 below.

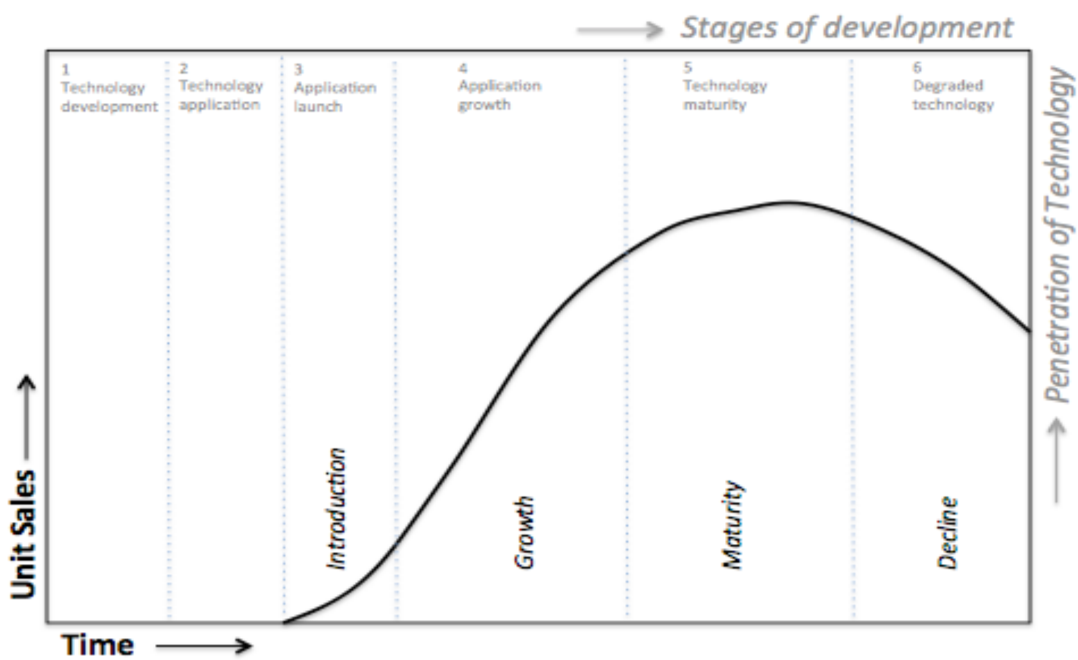


Figure 9: Product (market) life cycle (after Cox, 2007) ***overlaid with technology life cycle*** (after Ford & Ryan, 1981)

Product (use) life cycle comprising the stages involved in the economic life of a product, as used in financial analyses such as 'total cost of ownership', 'life cycle cost' *etc.* Typically used in comparisons for determination of most (life cycle) cost-effective alternatives, these types of economic models can be extended to include societal costs, in addition to direct manufacturing and use costs (Senthil, Ong, Nee, & Tan, 2003). The relative importance of the component of the life cycle cost of course will depend on the nature of the product, its application and the processes involved at the different stages of it life (*e.g.*, unmistakably for buildings, the length of lifespan is an important factor). Figure 10 below illustrates an example of such life cycle costs for a generic building in an area graph, where the shaded areas represent quantity of categorised costs total.

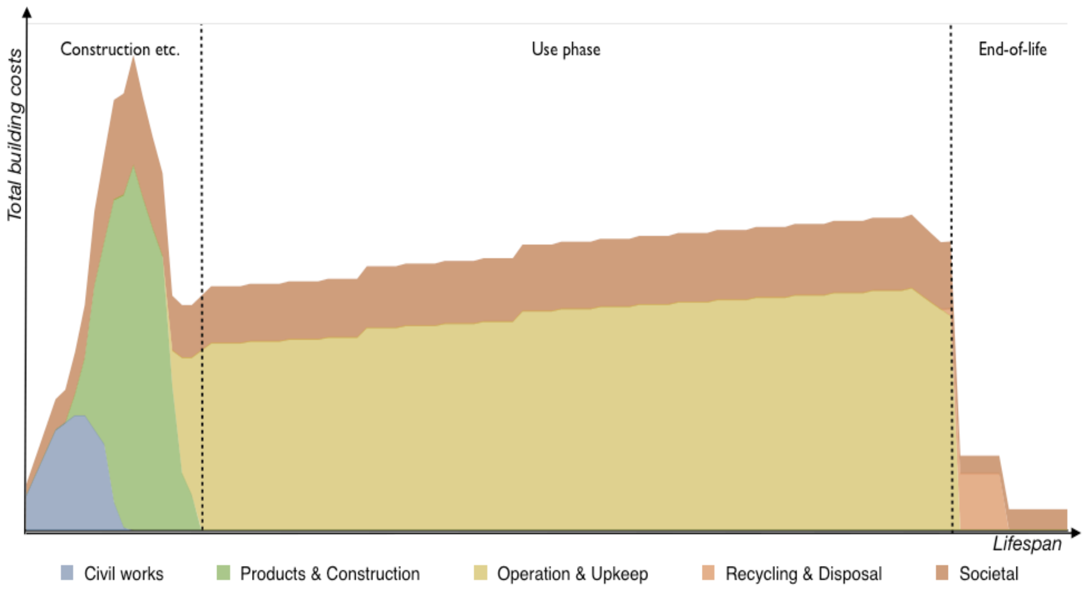


Figure 10: Illustrative building life cycle cost profile (derived from Alting, 1993; Barringer, 2003; Sherif & Kolarik, 1981; Woodward, 1997).

Figure 11 illustrates the same costs with instances of periodic renovation – note the peaks reflecting the additional costs associated with products and construction works and the recycling and disposal of waste generated from the renovation.

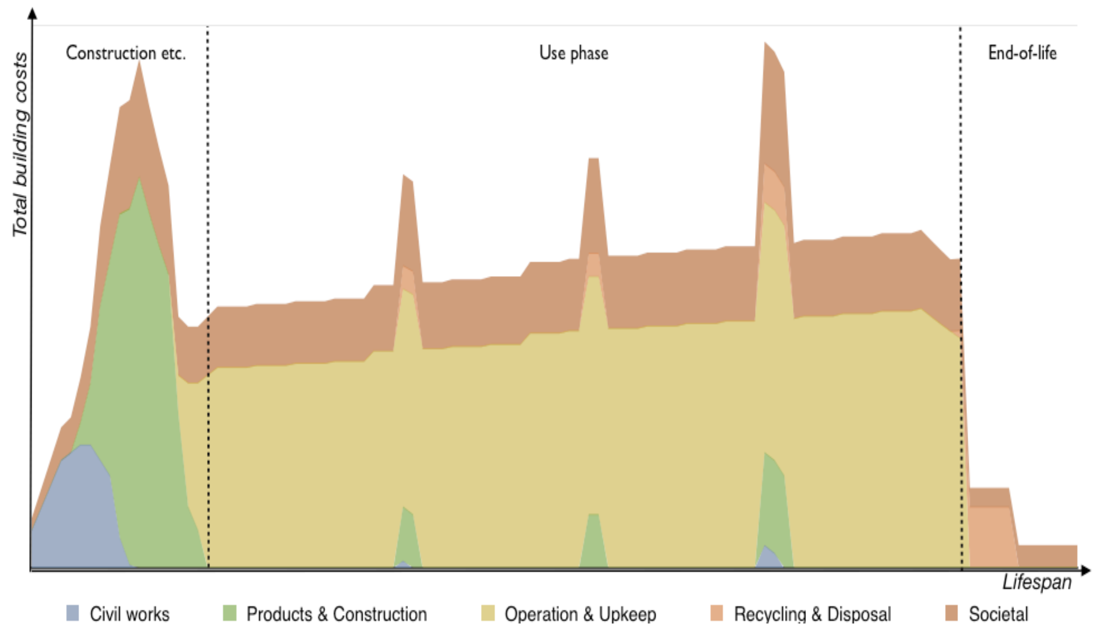


Figure 11: Illustrative building life cycle cost profile including instances of periodic renovation

Product (material) life cycle comprises the physical chain comprising the flows in materials and energy associated with the provision of the product, as used in life cycle environmental analyses (see for example, Guinée et al., 2001) and shown in Figure 12 below.

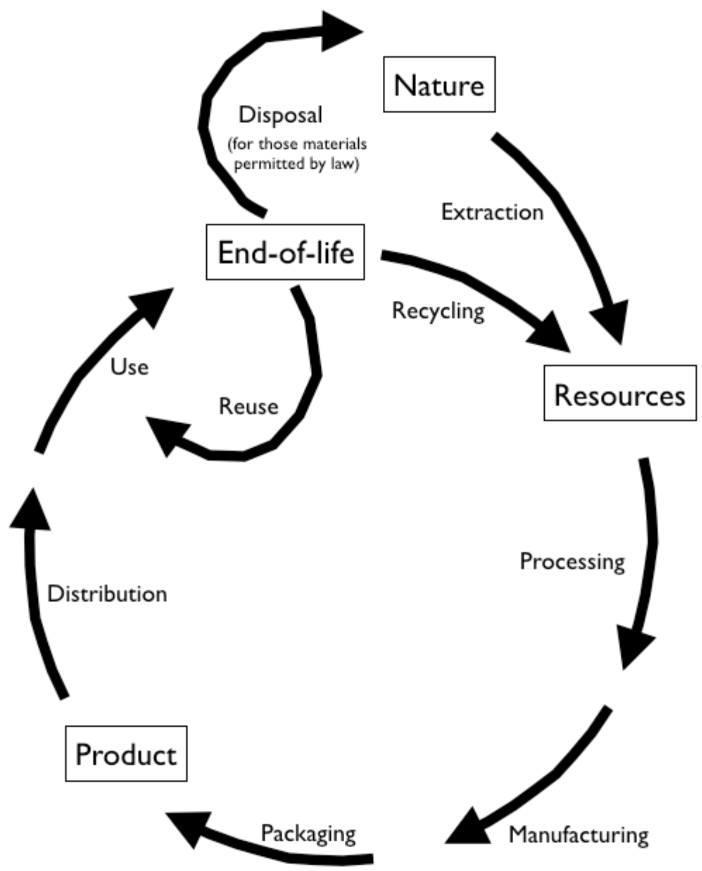


Figure 12: Generic (material) product life cycle (derived from Ansems, Van Leeuwen, Guinée, & Frankl, 2005, p. 21 and ; Fava & Hall, 2004, p. 6)

Each process in the life cycle results in consumption of both physical resources and energy resources and in the generation of wastes with consequential environmental impacts (Rebitzer *et al.*, 2004).

Figure 12 above offers a generic view of a life cycle, this is presented as an introduction to the 'physical chain' concept of life cycle that is central to the consideration of whole life environmental impacts (such as life cycle energy consumption and GHG emissions) and consequently a variant of the concept of interest to this thesis.

The specific case of the building life cycle will be discussed in some detail later in this section see for example Figure 13 on page 69. These differences in understanding of the life cycle concepts discussed above and presented in Table 4 below have the potential to cause confusion and therefore it is vital that there is clarity as to the meaning of 'life cycle' both in the design and conduct of a study but also in the communication of results[38].

Table 4: Different views on life cycle

Life cycle	Focus	Description
1. Product (market) life cycle	Focus on position in marketplace	Sales-orientated perspective considering market penetration over time encompassing introduction, growth, maturity and decline
2. Product (use) life cycle	Focus on economic lifespan	Economic life of building, including costs of building, maintaining, operating and ultimately demolishing the building when it is of no further use
3. Product (material) life cycle	Focus on whole life resource implications	Whole life perspective of buildings, considering flows of materials and energy, encompassing product, construction, operation and end-of-life stages

Indeed even within studies of the same type, differences in meaning arise, for example, Gluch and Baumann (2004) note that within life cycle costing, different kinds of life cycles may be considered *viz.*, economic, technical, physical and utility; while Guinée *et al.* (2011) observe that there are diverging approaches to boundary setting in life cycle environmental

[38] In such perspectives the design is not typically of a product is not considered part of the lifecycle — but it is of great importance as it will significantly shape the lifecycle

analyses. These differences can, and do impact greatly on the results of a life cycle study, whether examining financial, environmental or other metrics.

While a range of values accrue from building energy renovation projects, the principal metrics used to measure performance relate to financial returns, energy savings and GHG emissions avoidance. Understanding value flows across the lifecycle would therefore require a combination of the second and third life cycle perspective shown above. The stages of product (material) life cycle can also be adapted to form the basis of life cycle cost estimations of a renovation – this would enable an approach to be devised using a common definition of 'life cycle' for consideration of costings, energy consumption and greenhouse gas implications. ISO 14040 defines life cycle as the "*consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal*" (ISO, 2006a).

3.3.2 The life stages of a building

As noted previously, buildings are long-life complex entities, involving a combination of many different materials, components and systems, which have different replacement cycles and useful lives, and their various life cycles combine to form the building life cycle (Bekker, 1982; Cole, 1998). This life cycle comprises various processes, which combine to

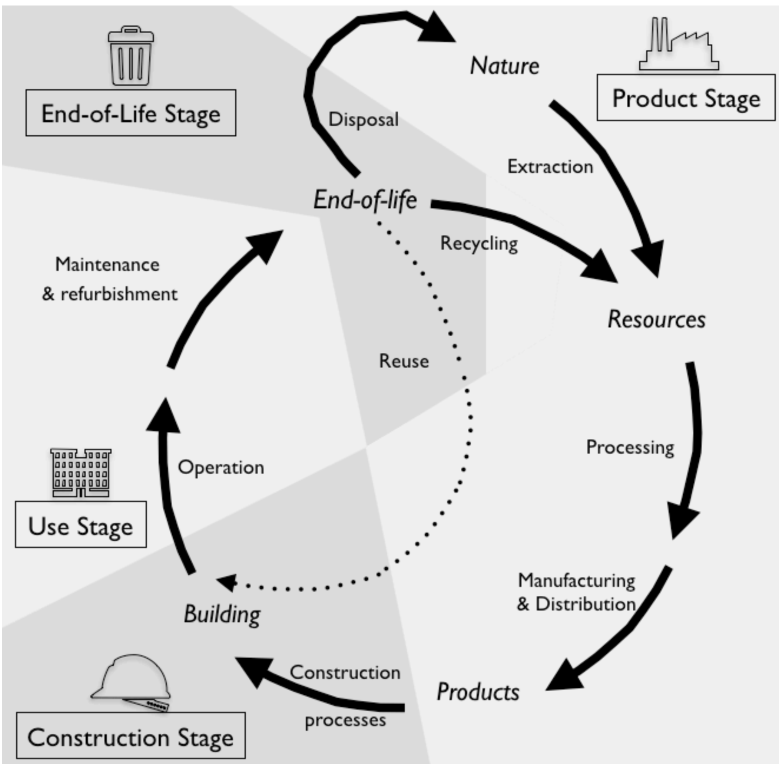
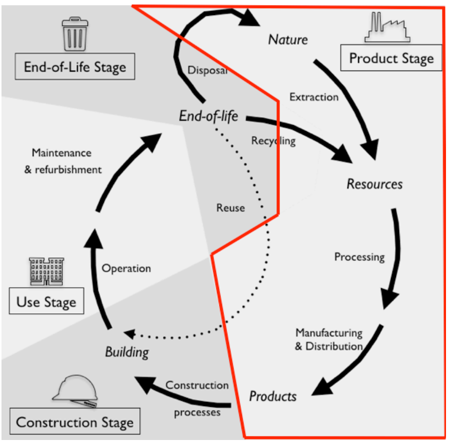


Figure 13: Building life cycle stages projected onto product life cycle model

deliver, operate and decommission a building. Different authors have categorised the building life cycle into varying number of stages (M. R. Fay, 1999; Sanvido, Kumara, & Ham, 1989). This has been (relatively) recently standardised – in the European context at least – by the publication of EN 15978:2011 (CEN, 2011b), which provides for four stages, namely: Product stage *i.e.*, raw materials supply, transport, and manufacture; Construction stage *i.e.*, transport and construction installation process; Use stage *i.e.*, operation, maintenance, repair and replacement, and refurbishment; End-of-life *i.e.*, deconstruction, transport, waste processing, and disposal. Projecting these four stages onto the generic product life cycle illustrated on page 67, results in Figure 13 which is presented above and discussed on the following pages.

Product stage



Industrial systems such as that which delivers and maintains the built environment are based on the consumption of resources from, and release of wastes to, the natural environment (see for example, World Commission on Environment and Development, 1987). The building life cycle can be said to commence when these raw materials, *e.g.*, aggregates, limestone, metal ores, wood, and fuels are mined, harvested or otherwise extracted from the natural environment. The extracted materials are then transported (sometimes over vast distances) from their site of origin to a facility, where they are refined or otherwise processed to produce materials of more use, *e.g.*, refining bauxite or iron ore. For many materials, these environmental impacts from the initial steps of raw material extraction and processing can be the very significant from an (environmental) life cycle perspective, *e.g.*, deforestation arising from unsustainable timber harvesting (Angelsen & Kaimowitz, 1999; Damette & Delacote, 2011; Fernow, 1897); the hazardous 'red mud' wastes produced from bauxite refining (Shannon & Verghese, 1976); habitat destruction, reduction in biodiversity and disruption to ecosystems services from mining and quarrying (*e.g.*, Assadi, 2002). (Note: the environmental impacts associated with extraction and processing is of course avoided through the use of recycled materials).

Next the refined and processed raw materials are transported to manufacturing facilities across the world where they are used in various combinations, in numerous processes to produce useful construction materials, *e.g.*, Portland cement, steel and aluminium. For more complex building components, production will involve a series of manufacturing, assembly and fabrication processes, often occurring in disparate locations (of course requiring further transportation), *e.g.*, windows, air conditioning units, intelligent façades (*e.g.*, Otreba & Menzel, 2012). Depending on the nature of the specific manufacturing operations, these steps result in various further environmental impacts including: the depletion of non-renewable resources; consumption of large quantities of energy and water; generation of non-hazardous and hazardous wastes; release of pollutants to air, land and water; destruction of natural habitats. See for instance LCA studies such as: Josa *et al.* (2004) on cement; Krogh *et al.* (2001) on steel; Tan and Khoo (2005) on aluminium; Syrakou *et al.* (2006) on windows; Heikkilä (2008) on an air conditioning system; and Soares *et al.* (2013) on a phase change material passive heat storage system.

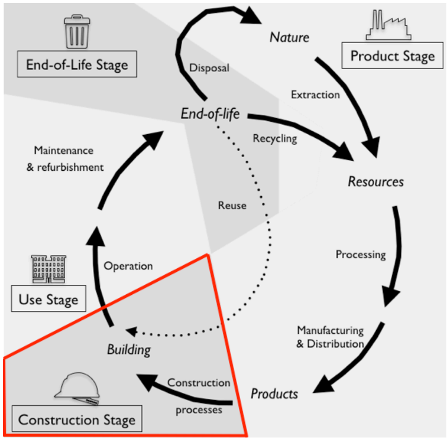
These building materials and components are either transported directly to the construction site (in the case of a large proportion of materials, *e.g.*, aggregates, concrete) or enter distribution systems whereby they are shipped to distributors' warehouses and onwards to wholesalers and/or retailers before being brought to the place of use. The transportation and other activities involved in the distribution of the materials and goods are particularly fossil-fuel energy intensive and accordingly result in substantial amount of GHG emissions (Mattila & Antikainen, 2011), notwithstanding the huge variation in energy consumption and GHG emissions associated with different modes of transportation (Kamakaté & Schipper, 2009; Schipper, Scholl, & Price, 1997).

In recent decades, a great deal of attention has been placed on making such processes more sustainable though the implementation of concepts such as 'clean technology' (*e.g.*, Markusson, 2011), 'cleaner production' (*e.g.*, Fresner, 1998), and 'industrial ecology' (*e.g.*, Lowe & Evans, 1995). Adopting these approaches through the use of various related tools such as Environmental Management Systems (*e.g.*, Darnall, Jolley, & Handfield, 2008), energy analysis (*e.g.*, Dobes, 2013), materials flows analysis (*e.g.*, Torres Rodríguez, Cristóbal Andrade, Bello Bugallo, & Casares Long, 2011), life cycle assessment (*e.g.*, Blengini *et al.*, 2012), design for the environment (Luttropp & Lagerstedt, 2006) has resulted in a reduction in the environmental impacts from manufacturing plants arising from:

- increased operational control, for instance through industrial licensing in line with the 2010/75/EU industrial emissions directive (EU, 2010b);
- cleaner production techniques, for examples as reported for alumina refinement by Borges, Hauser-Davis, & Ferreira De Oliveira (2011);
- cleaner sources of energy as illustrated by the reducing GHG emissions associated with Irish electricity, *e.g.,* 0.533t CO_2 per MWh in 2008 (CER, 2010) vs. 0.393t CO_2 per MWh in 2015 (CER, 2016);
- energy efficiency improvements, such as in the production of iron and steel (Worrell, Price, Martin, Farla, & Schaeffer, 1997);
- increased resource efficiencies, material substitution *e.g.* use of ground granulated blast furnace slag in place of Portland cement (Motherway & Walker, 2009, p. 22).

Notwithstanding such efforts, the environmental impacts of the product stage (so-called embodied impacts) remain substantial and present a significant challenge in reducing life cycle environmental impacts.

Construction stage

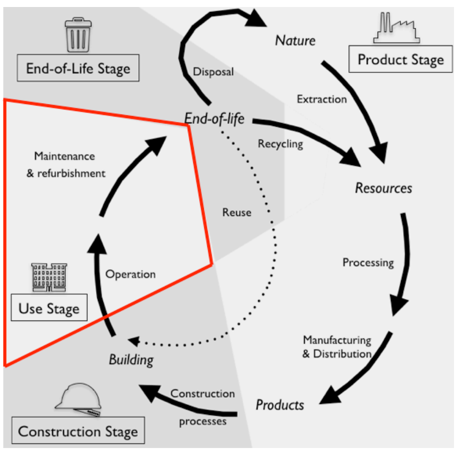


In the construction stage, the building materials and components produced earlier in the life cycle are combined and used onsite to construct and/or renovate a building. These onsite activities can result in significant environmental impact; the particular circumstances of each site and project means that there can be a wide variation in the environmental aspects of construction projects. Coventry and Woolveridge (1999) note a number of typical environmental issues for construction including: soil contamination; water pollution; generation of construction and demolition (C&D) waste; noise and vibration pollution; emissions; excessive dust; odours; ecological damage; archaeological destruction. Site management and work practices contribute greatly to the severity of such impacts: energy use is dependent on the efficiency of onsite plant and equipment operation, which can vary greatly from site to site; water consumption is affected by a number of issues, for instance the amount used in dust suppression; conversely the amount of dust particles generated depends on the effectiveness of dust suppression (which is at least partially dependent of the quantity of water used); the quantity of waste generated is a result of a number of factors, human error for example, can result in substantial increases in quantities of waste relative to comparable construction sites, as the result of poor workmanship, accidental damage, poor storage, incorrect/excess ordering *etc.* (Solís-Guzmán, Marrero, Montes-Delgado, & Ramírez-de-Arellano, 2009; A. T. W. Yu, Poon, Wong, Yip, & Jaillon, 2013).

The environmental impact of construction stage consists not only of the various onsite activities, commonly thought of as ‘construction’ but also the off-site support activities that feed into onsite work (including small contributors like draughtsmen and lawyers as well as more significant contributors like equipment maintenance and transportation) each of which have environmental impacts (including energy consumption). However, the influence of professional support services contributing to planning and design of the project goes far beyond the project-attributable environmental impacts of the architect's or engineer's practice. Their professional decisions and designs will directly impact the onsite (and indeed the operational) environmental impacts; this is especially evident with respect to the generation of waste[39]: a large amount of which originates as a results of poor design and conversely may be minimised through design choices (Baldwin, Poon, Shen, Austin, & Wong, 2009; Osmani, Glass, & Price, 2008).

An important step within this stage is commissioning of the building services to demonstrate "that the installed equipment has been selected, installed and commissioned in compliance with the design intent and specifications" (Oughton & Hodkinson, 2008). The quality of the work carried out in construction directly impacts the building performance during use, particularly from the point of view of energy consumption and associated emissions of greenhouse gases. Poor craft work will result in issues which will greatly increase operational energy demand (and associated emissions), including: incorrectly fitted insulation; thermal bridging reducing insulation efficiency, (Gomes, de Souza, & Tribess, 2013; Hassid, 1990); poorly commissioned equipment.

Use stage



The use or operational stage of the building is when the building is handed over for occupation for its intended use. While there are a number of environmental impacts associated with the use stage including waste generation, water consumption, effluent discharge, transport implications *etc.* However, for the vast majority of

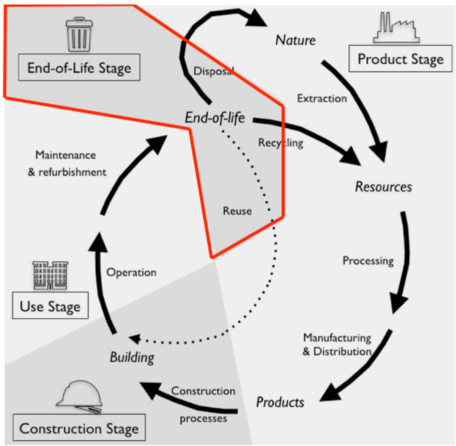
[39] All waste generated during a construction project represents wasteful upstream energy consumption and GHG emissions release

buildings, energy consumption is the single greatest impact during use (water consumption also being important in those regions where water is scarce). Buildings require energy for numerous functions including: light; heat and hot water; ventilation and air conditioning; sanitation; elevators and escalators; building management; security systems; in addition to general power for the utility of the building, whether it be computer stations for an office block, production machinery for a factory, or appliances in a domestic dwelling (Pérez-Lombard, Ortiz, & Pout, 2008). Notwithstanding the efforts to 'decarbonise' centralised energy grids within the EU (European Commission, 2011b) and elsewhere, in most cases, the energy systems feeding into these homes are still predominately fossil-fuel based – according to the IEA (2013), in 2009 fossil fuels still accounted for *ca.* 81% of worldwide energy production – with all that this entails in terms of the direct impacts of extraction activities, use of non-renewable resources, and the greenhouse gas emissions associated with their consumption (Solomon *et al.*, 2007).

As outlined on page 23, there are ongoing public policy efforts to increase building energy efficiency and thereby reducing associated carbon emissions. Parallel to, and partially in response to, the public policy and other drivers there has been continuous technological development in the design of buildings; the energy using systems within them, *e.g.*, HVAC; and the coordinated management of them, through sophisticated building management systems (*e.g.*, Yang & Wang, 2013).

During the use stage, timely and effective maintenance, repair, and replacement of building components is important to ensure they are working as planned and to provide for their optimal life span. While the materials and services used in the upkeep of the building components all have multiple environmental impacts; suboptimal maintenance will decrease asset efficiency (Mills, Kromer, Weiss, & Mathew, 2006), which will mean increased environmental impacts through suboptimal performance or shortened replacement cycles. For optimal performance of building services, concepts such as continuous commissioning are increasingly finding interest (Ahmed, Ploennigs, Menzel, & Cahill, 2010; Liu, 1999).

Renovation and refurbishment (often including retrofit of energy efficiency measures) are performed to upgrade, repurpose and increase the lifespan of a building. Such renovations may be minor and involve simply the replacement of certain components; while at the other extreme may involve substantial rebuilding around the structural frame of the building. The wastes generated during renovation and refurbishment (which can be quite substantial) are considered to have reached their end of life and are dealt with in the next section. Reuse of materials is a practical way of reducing both the cost of renovation and the environmental impact of same (Coelho & De Brito, 2012). By increasing the lifespan of the building, such renovation acts to increase the utility obtained from those environmental impacts already embodied in the building during its original construction and previous renovations.



End-of-life stage

Buildings and their component systems have a finite useful life and will eventually reach the stage where they will be decommissioned. The end of life stage consists of the deconstruction, dismantling and demolition of the building; waste handling and sorting; reuse and recycling; final disposal to landfill or incinerator of residual waste (where permitted by law); and, in so far as required, clean-up and restoration (and in extreme cases aftercare management) of the building site. At peak, in 2007 some 17.8 million tonnes of construction and demolition (C&D) waste were generated in Ireland, while this was reduced to *ca.* 3 million tonnes in 2011 just 4-years later (McCoole, Kurz, McDonagh, O'Neill, & Derham, 2013, p. 2), it is still a substantial waste stream and one that is directly linked with economic activity, with the 'normal' run rate likely to be somewhere between these two extremes. These activities involved in demolition and dealing with C&D waste can be very energy intensive and accordingly may have a large amount of associated GHG emissions (Dixit, Culp, & Fernández-Solís, 2013). Additional environmental impacts may arise as a result of: processes used to recycle material; incineration, *e.g.*, atmospheric emissions (Manfredi & Pant, 2014); and disposal of residual waste, *e.g.*, leachate from landfill (Wang, Sikora, Kim, Dubey, & Townsend, 2012; Weber, Jang, Townsend, & Laux, 2002). On the other hand net environmental benefits will arise from avoiding the extraction and processing of virgin material through recycling and to a lesser extent from the energy recovery processes (Carpenter, Jambeck, Gardner, & Weitz, 2012), which will offset at least some of the negative environmental impacts depending on the waste management routes chosen. Examples of such offsetting include:

- recycling of concrete materials will reduce the demand on quarries for new aggregate and reduce energy consumption, while at the same time ensuring this voluminous material does not take up landfill space;
- incineration of treated wood with appropriate emission scrubbers will safely dispose of material while also recovering energy.

In a scenario where life cycle energy is considered a priority, the reuse, recovery and recycling of products with a high embodied-energy could be a significant contribution towards such objectives. This is exhibited most clearly in the case of metals, for example aluminium production from bauxite is a highly energy intensive process compared to that from recycled processes. Hammond and Jones (2011) calculate 218 MJ energy used per kg of aluminium produced from bauxite ore, compared to 29 MJ/kg associated with that produced through recycling.

3.3.3 Conclusion

Section 3.3 explored the life of a building, it examined different meanings of life cycles and the relevance of them to building energy renovations. The product (material) life cycle was seen as the most relevant as its component stages could be used to devise a common basis for considering financial, energy and GHG emissions[40] implications of a building energy renovation project.

Section 3.4, which follows, explores the concepts and methods behind, and sets the basis for measuring multidimensional lifecycle performance (*i.e.*, financial, energy and GHG emissions) of building renovations.

3.4 Life cycle performance

3.4.1 Life cycle perspectives

Introduction

As noted on page 69, there are three basic objectives – and consequentially measures of success[41] – of building energy renovations. Firstly, the underlying objective of any energy renovation is of course to improve its energy efficiency *i.e.*, consume less energy while delivering the same service(s) (Patterson, 1996) – as such the energy savings achieved are an important performance metric for such projects. Secondly, as with any project investment, the financial return is an important consideration, closely linked to reduced energy consumption[42], this is typically calculated through methods such as rate of return on investment (Remer & Nieto, 1995a), profit to investment ratios, payback period (Remer & Nieto, 1995b), *etc.* There is also a third implicit objective of building energy renovations and while it may not be to the forefront of renovation project promoters, reducing the GHG emissions associated with buildings is a primary objective behind current EU and national policies, and the associated support instruments, which facilitate and support building energy efficiency renovations (*e.g.*, see EU 2030 climate & energy framework, European Commission, 2014).

[40] GHG emission implications could be considered as a subset of environmental impacts
[41] That is not to say that other values are not derived from renovation
[42] This of course means that it is subject to changes in the energy market price

Given the longevity and complicated nature of buildings, not to mention the complexity and likely changes in their use over their lifespan it is appropriate to consider such metrics on a life cycle basis. This is, in other words, a need for life cycle thinking (LCT). Manfredi & Pant (2014, p. 7) describe LCT as "*a conceptual approach that seeks to identify improvements and to lower the impacts of goods or services (products) at all stages of associated life cycles*". The concept of LCT aims to avoid burden shifting *i.e.*, where the problem is addressed by simply moving it to another life cycle stage, another region, another time or by transforming it into another type of problem. This type of holistic approach reduces the risk of environmental burdens being shifted between:

- Life cycle stages, *e.g.,* manufacturing phase to use phase;
- Geographical areas, *e.g.,* as in the case of off-shoring potentially GHG intensive work to countries with lower environmental standards;
- Environmental media, *e.g.,* reducing water emissions only to have consequential increases in atmospheric emissions (Fava & Hall, 2004)

Interesting, LCT also offers the potential for impacts such as considering carbon storage within buildings[43] (see *e.g.*, Buchanan & Honey, 1994).

While LCT is focused on environmental aspects (*e.g.*, resource use such as energy, environmental release such as GHG), the basic premise of life cycle thinking is also applicable to consideration of costs on a project level (for instance, there has been a lot of effort in attempting to integrate life cycle environmental and cost assessments *e.g.*, Brandão, Clift, Milà, & Basson, 2010 on multifunctional land use; Gu *et al.*, 2008 on buildings; Ristimäki, Säynäjoki, Heinonen, & Junnila, 2013 on district energy system design). The following sections will explore LCT with respect to building energy renovation.

[43] Whether carbon storage within building is considered 'negative' emissions *i.e.*, removal of CO_2 from the atmosphere, or temporal shifting is entirely dependent temporal perspective taken in boundary setting.

Conceptual Background

Life Cycle Assessment (LCA) is an environmental management method or tool used to identify and quantify the energy and material flows of a product system, their associated environmental aspects and the related impacts on the surrounding environment (Guinée et al., 2001). LCA can be considered as both a methodological approach to measuring, and a concept for understanding, the environmental aspects of products over their life-cycle (Vigon & Curran, 1993). ISO 14040 defines LCA as the "*compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle*" (ISO, 2006a).

Life cycle costing (LCC) or life cycle cost analysis (LCCA) is an accounting mechanism, which aims to estimate the total costs (of a good or service) over its lifespan. Life cycle cost is defined by White and Ostwald (quoted in Woodward, 1997) as "*the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life*".

It would appear that both approaches have potential as both 'accounting' tools and heuristic processes for considering products' environmental and economic performance from a whole life perspective. However, as mentioned previously in any life cycle assessment – whether it be cost, energy or environmentally focused – there is a need for clarity on definitions and assumption, in both designing a study and communicating its results. Trusty (2003, p. 2) makes the point that although quite separate conceptualisations, the approaches for life cycle environmental and life cycle costs assessments are potentially complementary. This section aims to review the conceptual and methodological context of life cycle assessment studies, of which life cycle energy and life cycle greenhouse inventory studies are subsets, and to which life cycle costing can be methodologically aligned.

Background to life cycle assessment

The first attempts at quantifying the life cycle environmental impacts of products date from the late 1960s and early 1970s. Originating in energy analysis, LCA has developed to encompass environmental impacts in a comprehensive fashion[44,45] (Guinée *et al.*, 2011). The methodological framework for LCA was initially developed through workshops organised by SETAC[46] in the early 1990s and was subsequently formalised in the ISO 14040 series of standards (Guinée et al., 2001). The series currently comprises two standards that form the basis of LCA practice today, namely: ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework (ISO, 2006a); ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines (ISO, 2006b).

The importance of such analyses becomes apparent when the nature of products' life cycles is considered. For example, the production of a common everyday product, such as a laptop, involves many complex and likely dynamic value chains with many different actors feeding in to the design and production of numerous individual parts. These are in turn assembled into components, which form the building blocks of the final product. This final product is distributed and used in various contexts over its useful life, before being disassembled, recycled and disposed. The flow of materials and energy within such a product life cycle will have significant environmental impacts, but identifying and quantifying such impacts requires the modelling and calculation involved in LCA.

According to ISO 14040/44, the aforementioned standards, which describe the principles, guidelines and requirements for life cycle assessments, the process comprises four principal stages, *viz.*: goal and scope definition; inventory analysis; impact assessment; and interpretation. These four stages, which are conducted in an iterative fashion, are shown in Figure 14 and described below (ISO, 2006a).

[44] Heijungs *et al.* (1992, p. 9) observe that this evolution from an analysis tool to an assessment tool explains the common alternate meaning of the LCA acronym, *viz.*, life cycle analysis.
[45] Indeed, current trends foresee further extension to include social aspects (Guinée *et al.*, 2011)
[46] Society of Environmental Toxicology and Chemistry

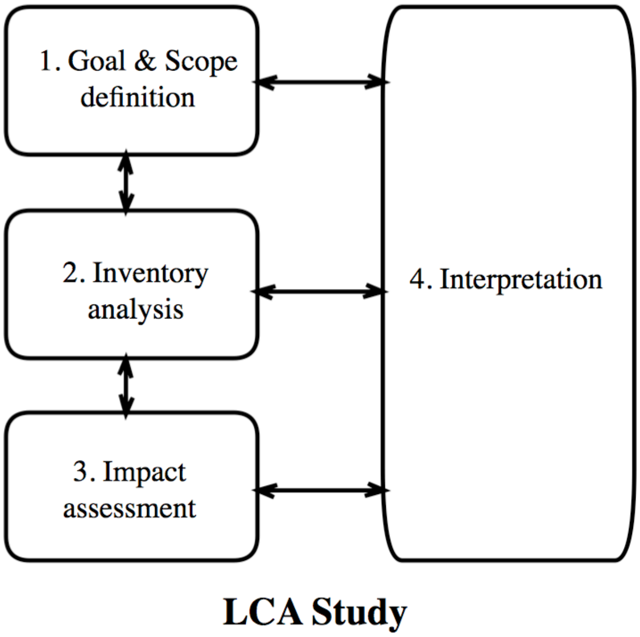


Figure 14: Methodological Framework of life cycle assessment (adapted from ISO, 2006a, p. 8)

1. The goal and scope definition stage is where the initial decisions are made that determine the shape of the study to be undertaken. This is a key task, which greatly determines the ultimate outcomes of a LCA study. The goal and scope should be established in terms of what information is required, for whom, for what reason and to what level of detail. An LCA may be commissioned for a number of reasons, *e.g.*, to identify those areas of the life cycle where significant environmental impacts arise – so-called environmental hotspots; to compare product variations or alternative processes; to make competitive comparisons in the marketplace, *etc.* The intended audience may be internal, *e.g.*, process improvement, or external, *e.g.*, customer communication, regulatory compliance. The study's scope is defined with respect to its temporal, geographical and technological coverage; and the subject of the study is described in terms of a so-called functional unit(s), defined by ISO as "*quantified performance of a product system*" (Guinée et al., 2001; ISO, 2006b), *e.g.*, the functional unit for a paint product could be defined as '1 m² surface protection for 10 years'. The use of a functional unit facilitates the comparison of alternative products.

2. Life cycle inventory analysis (LCI) involves modelling the product system and quantifying its environmental inputs and outputs. The system's activities are described

in a series of related and interlinking flow diagrams, which are used to identify, quantify and when needed allocate the inputs and outputs associated with each activity. The level of detail required for the process descriptions (and the associated amount of data collection) is dependent on the amount of detail required by the study's goal and scope. The input and output data is collected and stored in either generic databases or more commonly in LCA specific software such as SimaPro or GaBi. This data collection, comprising quantities of inputs and outputs associated with the functional unit, is known as the life cycle inventory (LCI) (Guinée et al., 2001; ISO, 2006b). The inventory analysis stage is closely linked to scoping, as experiences in data collection may lead to a refinement of the study's scope, as it will clarify what data is available and its accessibility.

3. The next stage, <u>life cycle impact assessment</u> (LCIA) involves assessing the potential environmental relevance of the LCI data through the use of indicators. LCIA evaluates the product life cycle, on a functional unit basis, in terms of selected impact categories (ISO, 2006b). Impact categories are selected on the basis of their relevance for the study goal; examples of impact categories include: climate change, eutrophication, land use, ozone depletion, acidification, nitrification, *etc.* (Pennington *et al.*, 2004).

4. The <u>interpretation stage</u> comprises phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations (ISO, 2006b).

It is recognised that studies will not always require the full four-stage methodological framework of LCA discussed above – there are cases where the goal of the study will not require the impact assessment stage, such studies are referred to as life cycle inventory (LCI) studies, see Figure 15 below (ISO, 2006a, 2006b). The ISO 14040/44 standards can therefore provide the framework for both an LCI study, wherein for example GHG gases are separately accounted or for a (partial) LCA study wherein the quantum of GHG is converted to the global warming potential (GWP) life cycle impact category (Finkbeiner, 2009).

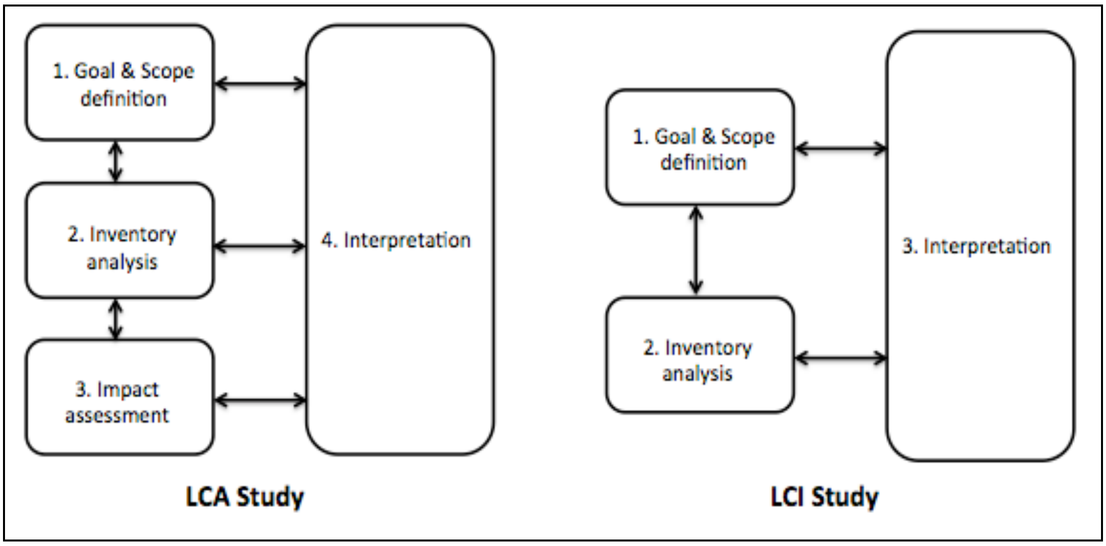


Figure 15: Methodological Framework of LCA and LCI studies (adapted from ISO, 2006a, p. 8)

While acknowledging that building performance has other dimensions, quantifying building performance for those three life cycle metrics mentioned previously requires the preparation of life cycle inventories relating to cost, energy and greenhouse gas emissions *i.e.*, life cycle cost analysis (LCCA), life cycle energy analysis (LCEA) and life cycle inventory analysis (LCIA) of GHG. The relevant LCA stages are therefore (i) goal and scope definition, (ii) life cycle inventory analysis and (iii) interpretation. As mentioned previously determination of the quantum of lifecycle resource use, such as energy and life cycle environmental releases, such as GHG is exactly the task for which these LCA stages were designed. The estimation of projected life cycle costs (life cycle cost inventory) requires use of life cycle costing techniques – but this too can be aligned to the three aforementioned LCA stages. The following section will review the methods of these three inventories.

3.4.2 Life cycle costs

Introduction

As mentioned on page 80, life cycle costing is an estimation of the total cost of goods over it useful life. Formalised life cycle costing (LCC) is said to have originated for use in the procurement of weapon systems in the mid 1960s within the US Department of Defense, and thereby the wider American defence industry (Busek, 1976, p. 9; Sherif & Kolarik, 1981).

Sherif & Kolarik's (1981) illustration of phase cost relations, shown in Figure 16 below, identifies three phases for a generic product system *i.e.*, research & development, acquisition investment, operation & maintenance (Woodward (1997) refers to these as engineering & development, production & implementation, and operating costs respectively). It is notable and perhaps reflective of the times, that in this view end-of-life costs were not explicitly treated in the original graphic, typically such costs would now be included (*e.g.*, Asiedu & Gu, 1998) and have been added here.

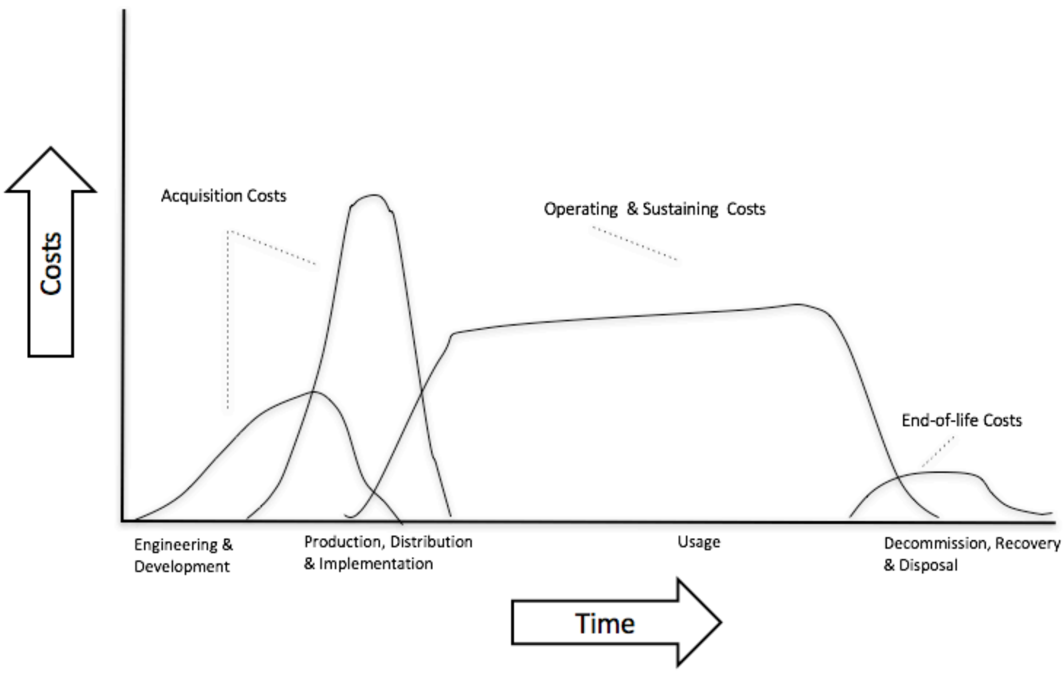


Figure 16: Generic phase cost relations for a system (derived from Sherif & Kolarik, 1981, p. 291)

The relative significance of each phase's costs will be substantially different from product to product (and indeed even within product classes). For many products, the cost of acquisition (which in Figure 16 above include both R&D and acquisition investment) will account for the vast majority of the life cycle costs, this however would not always be the case. For example, as can be seen in Figure 10 and Figure 11 shown on pages 66 & 67, the operational phase would be more significant or even dominant in long-life products especially those with relatively high operating costs such as buildings.

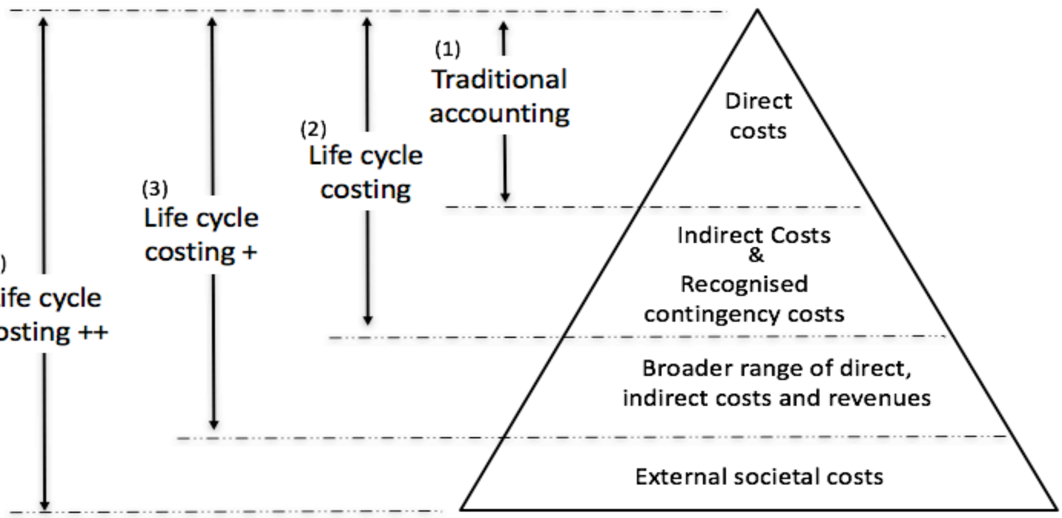


Figure 17: Alternative cost accounting methods (derived from Cole & Sterner, 2000, p. 369)

Gluch & Baumann (2004) observe a confusing range of life cycle accounting concepts. They present an overview of ten tools looking at life cycle costs and note that some have different names, but similar conceptual foundations, while other share the same name but are based on very different concepts. Cole and Sterner (2000) identify a number of different cost accounting methods which aim to reflect costs additional to acquisition as shown in Figure 17 above.

Traditionally, only the initial direct costs of acquisition would have been registered as shown by (1) on the illustration. Life cycle costing (2) expands upon this to include estimates of the future indirect costs associated with operation. Variants of life cycle costing can be further expanded to include for example the costs and revenues associated with use of a product (3)[47]. There has been substantial effort in expanding life cycle costing to include, for example, environmental burdens as in (4) in Figure 17. However, this is problematic, and Gluch & Baumann (2004, p. 574) observe that due to its *"basis in neoliberal economic theory LCC handles environmental aspects insufficiently"*, by which they infer that costing environmental aspects is difficult under a free market economic

[47] This would correspond with what ISO15686-5 refers to as whole-life costing (ISO, 2008b, p. 3)

model.

Consideration of externalities in such a matter is very troublesome, not least because their value is by their nature unquantifiable – how does one place a value on for example biodiversity? Thus, there are many shortcomings with using life cycle costing for environmental reasons, including (Gluch & Baumann, 2004 unless otherwise stated): conversion to monetary unit is simplistic and subjective (not to mention, likely impossible); there are ill-defined property rights in the natural world; LCC is unable to handle irreversible decisions (*e.g.,* species extinction), as it assumes there are always alternatives; it also handle uncertainty poorly; it relies on a lot of estimated variables; cost data will have geographical, currency, and time dimensions (Ciroth, 2009); discounting rates applied to such costing inherently means inter-generation impacts such as climate change will not be afforded due consideration[48] (Hampicke, 2011).

Building life cycle costs

ISO15686-5:2008, which provides general guidelines for life cycle costing of buildings, defines LCC as "*a methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope*" and note that it can address the entire life cycle or selected stages (ISO, 2008b). Gluch & Baumann (2004) report that the first attempts to apply LCC to buildings were in the 1980s, while there are reports of somewhat similar thinking in 'cost-in-use' approaches applied to buildings in the UK as early as the 1950s (Ashworth, 1993 cited in Öberg, 2005, p. 28).

Kneifel (2010) describes LCC of buildings as estimating the costs associated with acquiring and operating a building over a period of time, including costs associated with: construction; maintenance and repair; replacement of components; energy consumption; *etc.* To enable comparisons of costs and revenues from different time periods, future transactions are discounted to their equivalent present values based on the relevant

[48] The inherent uncertainty of future impacts is also significant *e.g.,* the likelihood of tipping points which cannot be assessed with any great confidence.

discount factors, and thereby deriving a net present value of the costs (Gluch & Baumann, 2004). Öberg (2005, p. 29) highlighted the importance of the discount rate to LCC calculations, with lower discount rates increasing the value placed on a future event and a zero discount value making temporal differences irrelevant[49]. The typical life cycle costs associated with a building can be divided into those costs embodied in the structure of the building so-called embodied costs, those costs that are required to operate the building, and end of life costs, as shown in Figure 18 below (see also Figure 21 on page 95, Figure 23 on page 100, which give a similar over view of life cycle energy and greenhouse gas emissions respectively).

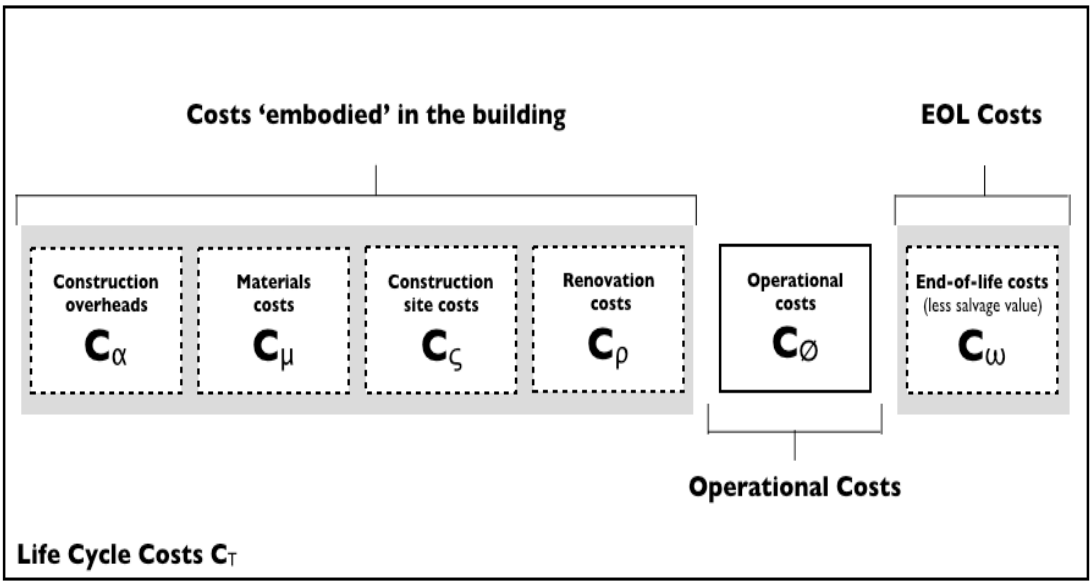


Figure 18: Overview of constituents of a building's life cycle costs

3.4.3 Life cycle energy

Introduction

Since the earliest times energy of some form or another has played an important role in the development of our civilisation, an adequate supply of energy is required to provide the basic necessities of life, such as shelter, food and clothing. Accordingly, energy can be considered an essential building block of society. This importance is underscored by the comments of Nobel-prize winning physicist, Frederick Soddy who said in 1926 "*If we have energy, we may maintain life and produce every material requisite necessary. That is why*

[49] In principal the discount rate should be equal to the alternative cost of capital, which obviously differs between entities (Öberg, 2005, p. 29)

the flow of energy should be the primary concern of economics" (Clark, 1989, p. 127).

Energy analysis can be thought of as a study of the flow of energy in society. As mentioned previously, the 1970s oil crises raised energy to the top of public policy considerations, Alessio (1981) argues that energy analysis became of far more interest to policy makers once the OPEC cartel was formed and gives the example of the US 1974 Non-Nuclear Energy Research and Development Act, which introduced a legal requirement for energy analysis (albeit that there was no consensus on what this meant) [50].

Energy is such a fundamental part of all human activities that an energy analysis necessitates a life cycle approach to capture all the energy requirements represented by a particular system *e.g.*, in the case of a product system, this would entail not only the energy consumed directly during production, but also all energy consumed associated with the production and/or provision of equipment, materials and services needed for manufacturing. Boustead & Hancock (1979, cited in; Fitch & Smith Cooper, 2004) defined energy analysis as "*a technique for examining the way in which energy sources are harnessed to perform useful functions"* giving the example of production and recycling of metals. One of the first such energy analysis studies is Harold Smith's 1963 report at the World Energy Conference of cumulative energy requirements for the production of chemical intermediates and products (SAIC, 2006, p. 4).

[50] It may be that Alessio is conflating OAPEC, the Organization of Arab Petroleum Exporting Countries (which was founded in 1968 and proclaimed the 1973 oil embargo) with OPEC, the Organization of the Petroleum Exporting Countries, which was founded in 1960.

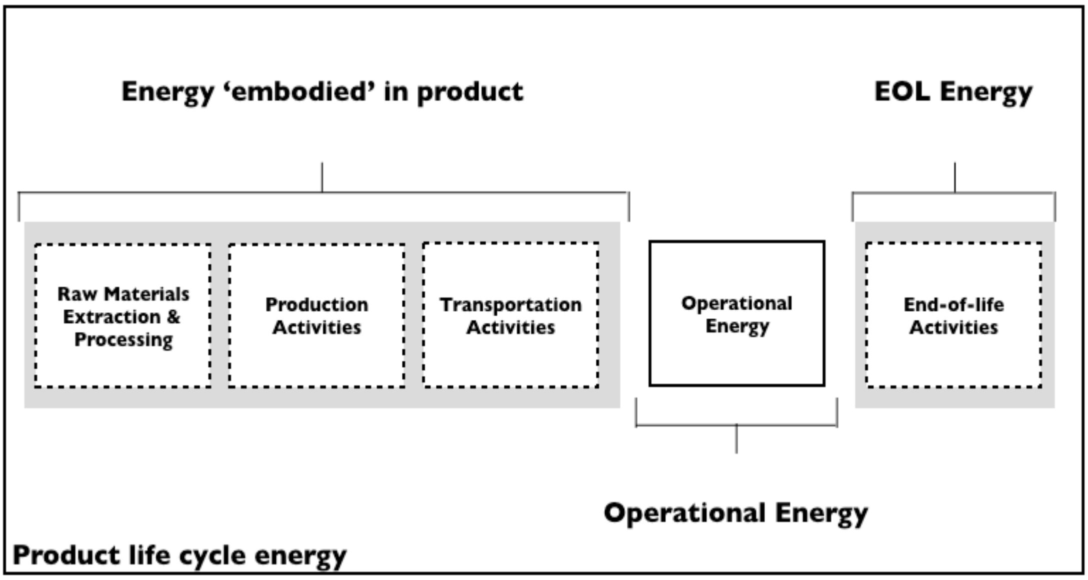


Figure 19: Generic constituents of product life cycle energy

The above figure disaggregates the energy associated with a generic product over its life. The sum of energy consumed in the manufacture of the product is said to be embodied *i.e.,* that energy associated with the extraction and processing of raw materials, manufacturing operations and transportation activities are seen as incorporated in the product. Costanza (1980, p. 1219) describes embodied energy as "*total (direct and indirect) energy required for the production of economic or environmental goods and services*". Operational energy of a product is that energy consumed through use over its useful life, for some products this could be quite substantial (*e.g.,* motor vehicles[51]), while for others it will be negligible or irrelevant. The final constituent of life cycle energy is that associated with the recovery, recycling and/or disposal activities which occurs when a product's useful life comes to an end.

Primary Energy or Secondary Energy

Primary energy can be thought of as the energy inherently present in natural energy resources before undergoing any transformation[52], *e.g.*, chemical energy of fossil fuels such

[51] Danilecki, Mrozik, & Smurawski (2017) offer an interesting summary of interaction between life-cycle stages for the manufacture of cars. They detail the trade-offs implicit in the use of lighter materials to increase operational energy efficiency of vehicles – with the energy savings achieved over the average life of a car being more than off-set by higher quantity of energy used to produce the new materials.

[52] Primary energy *i.e.* energy inherently present in a fuel should not to be conflated with a product's embodied energy, which describes the energy consumed to deliver that product.

oil; chemical energy of biomass; radiation energy of uranium; solar energy from sunlight; kinetic energy from moving water and wind; thermal energy from geothermal boreholes, *etc.* (Cleveland & Morris, 2006, p. 346).

Øvergaard (2008) identified the key characteristic of primary energy as the process of extraction or capture with the physical and chemical characteristics of the energy being unchanged. She presents the example of hard coal, which may be cleaned and graded but otherwise unchanged, as a primary energy source. Contrast this with the related fuels of lignite and peat, which are dried and processed into briquettes, and which are considered secondary fuels. These primary energy sources undergo energy conversion processes to be transformed into more useful forms of energy, such as electrical energy[53] and refined fuels, which are termed secondary energy sources as shown in Figure 20 below.

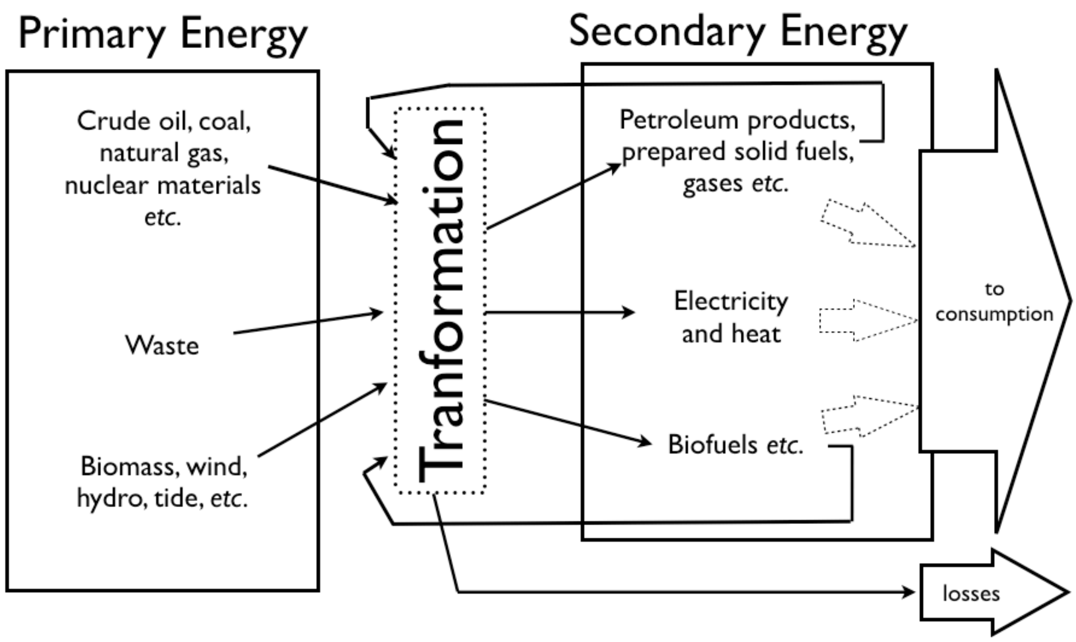


Figure 20: Primary and secondary energy (adapted from Øvergaard, 2008, p. 5)

The energy delivered to end-users is a mixture of primary fuels (*e.g.*, coal and natural gas) and secondary fuels (*e.g.*, electricity and refined fuels). The industries, which produce and distribute the fuels themselves use energy, conversion to secondary fuel will have losses from entropy, additionally there are losses through the distribution system (Hulscher,

[53] Other sources have distinguished between the source of the electricity, classifying electricity from renewables as primary energy, Øvergaard (2008) however argues convincingly otherwise on the basis of consistency and clarity.

1991). It can be seen therefore that the energy delivered to site is not the complete energy consumption associated with the site's activities; Marszal *et al.* (2011) also observe that the different qualities of energy delivered are also ignored, when considering delivered energy alone. It is apparent then that consideration of product life cycle energy consumption (whether of a generic product or a building) must be addressed in terms of primary energy and not delivered energy.

Alternative perspectives on energy

By definition, the *raison d'être* of the building energy retrofit industry is reducing energy consumption. However, consuming energy might strictly speaking be considered a misnomer as consumption would contravene the first law of thermodynamics; what is occurring in actuality is a transformation from one form of energy to another (Hulscher, 1991) with a degradation of quality of energy (Rebane, 1995), *e.g.*, chemical energy in oil converted by a furnace to thermal energy for space heating. This is an important distinction and the idea of entropy can prove useful in analysing complex interactions over a life cycle. Energy analyses are an important part of designing retrofit projects, however, energy analysis has been criticised for a number of reasons, such as: the unsuitability of using energy alone as an indicator of resource use (as is often the case) and the inclusion of different forms and qualities of energy in one total (Nilsson, 1997).

There are a number of concepts, which are suggested either as a replacement for, or a complement to, conventional energy analysis to address these supposed shortcomings. First, the concept of Exergy is forwarded as a potential solution to the issue of measuring energy consumption or savings (Shukuya, 2009), while also resolving the perceived artificial distinction between energy forms. Exergy, a term first coined by Rant (1956), is an environmental metric that provides a measure of the (theoretical) maximum useful work available from a thermodynamic system – the 'available energy'. It is the maximum amount of work[54], which can be provided from the system as it achieves equilibrium with its environment (M. A. Rosen & Dincer, 2001). Like energy, exergy is also measured in joules, however unlike energy, exergy is not subject to the conservation law and can be consumed and destroyed (Sato, 2004). Shukuya (2009) argues that exergy analysis should be applied to buildings; he opines that knowledge of the quantity of exergy introduced, where and how it is consumed, and how the entropy generated as a result of exergy consumption is discarded will lead to a better understanding of building systems and to more sustainable built environment. Baldi & Leoncini (2014) show how exergy analysis could be used to explore the thermodynamic interaction of buildings and their surroundings, providing an estimate of inputs and exergy destruction[55].

Deriving from the work of Odum (1988, 1996), Emergy (spelled with an 'm') is another concept emanating from (or associated with) energy – it attempts to quantify the relationship between human-made systems and the biosphere (Pulselli, Simoncini, Pulselli, & Bastianoni, 2007) through the estimation of the available energy of one kind used in the entire supply chain to generate products, provide services *etc.* (Raugei, Rugani, Benetto, & Ingwersen, 2012). The metric used is solar emergy, defined by Sciubbaa & Ulgiatib (2005) as "*the sum of all solar exergy directly or indirectly input to a process*" – non-solar derived inputs, *e.g.*, geothermal are converted to solar equivalent exergy through the use of transformation coefficients. Marvuglia, Benetto, Rios, & Rugani (2013) observe the rationale of emergy is that all the different forms of energy can be sorted, transformed measured with the common metric of the solar emjoule (sej), providing a basis for the comparisons of energy and material flows. Emergy has been described as a very specific case of embodied solar calories[56], and the two concepts have some similarities however

[54] Thermodynamic Work defined as energy transfer across the boundary of a system (Klein & Nellis, 2011, p. 117).
[55] Exergy is destroyed when a process is irreversible, for example loss of heat to the environment
[56] Embodied solar calories was confusingly originally known as embodied energy, a term now reserved for a very different concept, discussed earlier in this chapter (Brown & Ulgiati, 2004).

there are significant differences[57] [58] (Brown & Herendeen, 1996). Sciubbaa and Ulgiatib (2005) posit that emergy analysis offers a "*donor system of value*" – value is measured according to the value taken from the environment; while other common analyses such as exergetic analysis and economic evaluation are "*receiver systems of* value", value is measured according to its usefulness to the end user. In analysing energy consumption from a resource conservation perspective, emergy could be a useful approach.

Building life cycle energy

Buildings consume energy throughout their life, not just during their operation phase. A building's life cycle energy requirement is a total of the energy attributable to the building over its life span (Yohanis & Norton, 2002), including:

- initial embodied energy *i.e.*, sum of energy inputs used to manufacture materials and construct of the building (G. P. Hammond & Jones, 2008);
- Recurrent embodied energy added periodically to the building though maintenance, renovation, *etc.* (Dixit, Fernández-Solís, Lavy, & Culp, 2010);
- operational energy consumption (which may be measured or modelled);
- embodied energy associated with the end-of-life management of the building (Yohanis & Norton, 2002).

[57] Emergy being defined usually as solar energy with other energies expressed in equivalent solar energy, whereas embodied solar calories is based upon the fuel calorific value or equivalent (Brown & Herendeen, 1996).
[58] Non-inclusion of environmental support, from solar, geothermal and tidal sources, and human input in embodied energy calculations (*Ibid*.)

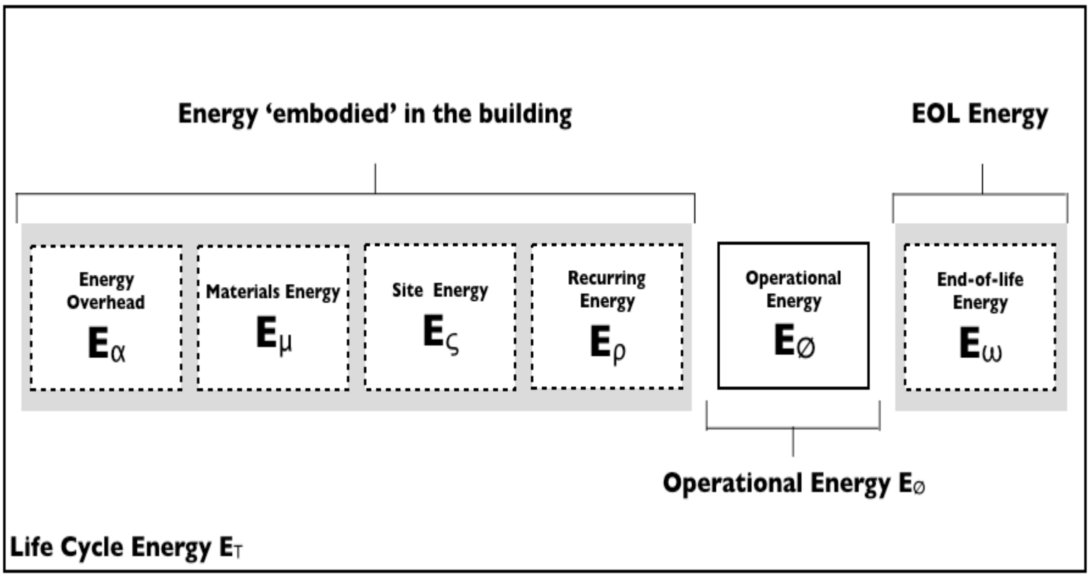


Figure 21: Overview of the constituents of a building's life cycle energy

Figure 21 above shows a slightly modified version of life cycle energy specified for buildings. In the graphic, E_T is the sum of energy consumed across the life of the building; $E_{\varnothing}$ is the operational energy consumption; E_E is the embodied energy consumed *i.e.*, that energy that was consumed in the activities required to construct, maintain, renovate and deconstruct the building. Embodied Energy can further be disaggregated[59] into following components:

- $E\alpha$ is the energy consumption associated with the project management activities including those involved in delivering the building;
- $E\mu$ is the energy consumed in the various processes involved in the manufacture and supply of materials and products for the building;
- $E\varsigma$ is the onsite energy consumption by various activities and services that go into constructing and commissioning the building;
- $E\rho$ is the energy consumption associated with the materials, goods and activities that go into the periodic refurbishment and renovation of the building and from the waste management activities associated with the wastes generated during refurbishment and renovation;

[59] Establishing the boundaries for each component is undertaken as part of the goal and scope definition stage of life cycle assessment as discussed on page 64.

- Eω is the end of life energy *i.e.,* the net energy consumption emissions resulting from the deconstruction, recovery, recycling and disposal activities (including positive flows such as energy recovery) at the end of the building's (or a part of its useful life.

Figure 21 can also be said to represent a collection of life cycle energy computations for each of the materials represented by E_μ & Eρ components).

Notwithstanding the consumption of energy across the different stages of the building's lifespan, current approaches to seeking energy savings from buildings, concentrate on so-called operational energy and in so doing, consider only part of the equation. While the historical ratio of operational and embodied energy may have justified such approaches in the past – this is no longer necessarily the case. As buildings become more efficient, using less energy in their operations the embodied energy component automatically accounts for a greater proportion of life cycle energy. Thus, even putting to one side potential increases in the absolute amount of embodied energy of buildings (use to increased processing and additional technologies, etc.)[60] It can be seen that its relative significance will increase. An indication of this trend is shown by Sartori and Hestnes' (2007), review of 60 case studies, in which they found embodied energy accounted for 2-38% of lifecycle energy for conventional buildings, compared to 9-46% for (more) energy efficiency buildings. As buildings' efficiency increases, so too will the proportion of embodied energy.

However, the historic focus on buildings' operational phase was justified as it was in keeping with many life cycle energy assessments of conventional office and residential buildings, which showed for typical buildings a large majority of total energy consumption was accounted for by operational energy (Wallhagen, Glaumann, & Malmqvist, 2011). For instance, Yung, Lam & Lu (2013) conducted an "*audit of life cycle energy analyses of*

[60] Additional materials required for insulation and to make buildings more air tight will typically mean an increase in embodied energy for energy efficient buildings, However, Sartori and Hestnes (2007) interestingly note that (some) passive houses designs, (due to the absence of a conventional heating system) can achieve large reduction to lifecycle energy with only a small increase in (absolute) embodied energy.

buildings" in which they reviewed 206 LCEA case studies found in 36 research works, and calculated that on average the initial embodied energy expressed as number of years of annual operational energy was 7.8 years for offices and 7.5 years for residential buildings. While for some types of buildings, (*e.g.,* warehouses, high energy efficiency designs), it was accepted that non-operational (*i.e.,* embodied) energy could be of far more significance (Lane, 2007; Sturgis & Roberts, 2010), it was almost a truism, as Ramesh, Prakash, & Shukla (2010) posited, that operational energy was the most important aspect for the design of buildings with lower life cycle energy demand.

However, increases in the energy efficiency of buildings and the additional embodied energy associated with such improvements mean that embodied energy is increasing in significance and it is no longer appropriate that it be disregarded in decision-making. In the context of energy retrofit of buildings, it is obviously important that decision-makers can be confident that the quantity of embodied energy being 'invested' in a retrofit is less than the quantity of operational energy, which will be avoided or 'saved' for the expected remaining life of the building. This means that life cycle energy analysis is of growing importance in the construction sector, and that each element of life cycle energy be considered in evaluating the energy implications of renovation[61].

3.4.4 Life cycle greenhouse gases

Introduction

An important driver of public policy initiatives to reduce energy consumption derives from the objective of stabilising atmospheric greenhouse gas levels by limiting their emissions. Another approach to evaluate the success of energy efficiency initiatives is to consider the life cycle effect on such emissions.

The so-called carbon footprint is another related concept of LCA, it is a measure of the

[61] Certain renovation options could for example result in a greater amount of energy 'expenditure' i.e. embodied energy than would ever be recovered through reduced consumption over the expected life of the renovation

greenhouse gases associated with a product, service, organisation or other defined system. The concept originated in the discourse of ecological foot-printing in the late 1990s. There is a lack of consensus on the exact meaning of the term, but there is broad agreement that it is a quantitative expression of gaseous emissions associated with climate change that are associated with human production or consumption activities. The scope of definitions ranges from measures of direct CO_2 emissions only to full life-cycle greenhouse gas emission inventories, and not even the units of measurement are agreed by all[62] (Wiedman & Minx, 2008; Wright, Kemp, & Williams, 2011).

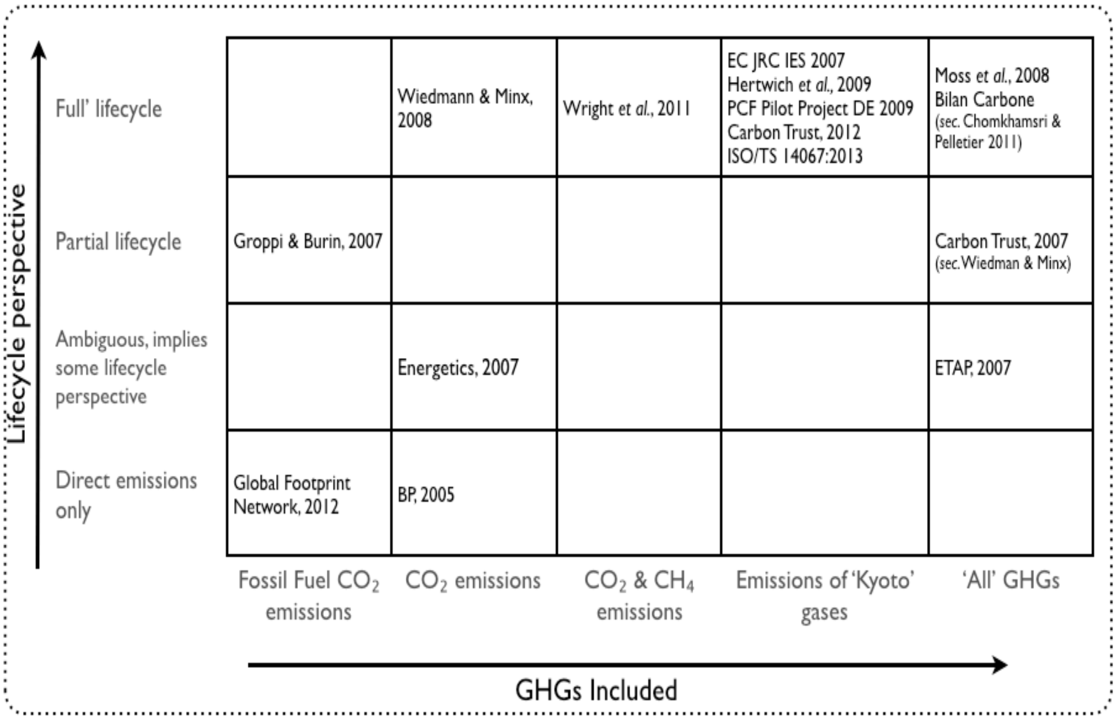


Figure 22: Spectrum of 'Carbon Footprint' definitions

Figure 22 above maps these various definitions and illustrates the range that exists in both the 'grey'[63] and peer-reviewed literature (BP, 2005; Carbon Trust, 2012; Chomkhamsri & Pelletier, 2011; Energetics, 2007; GFN, 2012; Groppi & Burin, 2007; Hertwich & Peters, 2009; ISO, 2013; JRC-IES EC, 2007; Moss, Lambert, & Rennie, 2008; PCF Pilot Project Germany, 2009; Wiedman & Minx, 2008; Wright et al., 2011).

[62] While most quantify 'carbon footprint' in terms of mass of emissions, some for example the Global Footprint Network express the measure as 'the demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion' *i.e.* hectares (GFN, 2012)

[63] Non peer-reviewed material such as technical reports and public policy briefings, *etc.* (Banks, 2006)

In acknowledging such differences, Peters (2010, p. 245) recommends the following open definition: "*the 'carbon footprint' of a functional unit is the climate impact under a specified metric that considers all relevant emission sources, sinks, and storage in both consumption and production within the specified spatial and temporal system boundary*". Depending on the scope selected for, and the approach taken in the preparation of a particular carbon footprint, it will be related to a greater or lesser extent to LCA, with those studies following LCA guidance resulting in a life cycle inventory of greenhouse gases i.e. essentially a subset of an LCA study.

Determining a life cycle GHG inventory[64], involves calculating the quantities of individual greenhouse gases emitted as a result of the various activities attributable to the system under review; these quantities are then converted to carbon dioxide equivalents (CO_2e) using global warming potential factors, *e.g.*, from the Intergovernmental Panel on Climate Change, IPCC (Forster *et al.*, 2007) and a carbon footprint is expressed in terms of mass of CO_2e. There are two principal types of such inventory: Product-focussed *i.e.,* "*a measure of the greenhouse gas emissions across the life of a particular product throughout its life cycle*" and the organisation-focussed, which "*measures the direct and indirect GHG emissions arising from all the activities across an organisation"* (Wiedman & Minx, 2008). As there is no one definition of carbon footprint or GHG inventory it is important that the communication of findings details all underlying assumptions and explains the approach undertaken.

Buildings' life cycle greenhouse gases

The GHG footprint of a building over its life cycle has been termed life cycle carbon (Kneifel, 2011) or whole life carbon (B. P. Smith, 2008) emissions – in effect such measurements are life cycle inventories of greenhouse gas emissions. This term is used in preference in this document to distinguish between life cycle studies which follow appropriate LCA guidelines

[64] Assuming it is defined as full life cycle inventory of the 'Kyoto gases' *i.e.* those gases listed in the Kyoto protocol to the UNFCC, *viz.,* CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 (UN, 1997)

and those which may not. As noted previously, reduction of such emissions is increasingly an important complementary objective of building energy retrofit projects. Just as buildings consume energy throughout their life, they are also responsible for GHG emissions. Life cycle inventories of greenhouses gases can be calculated through Life Cycle Assessment based methodologies giving the total GHG emissions generated over the life of a building (including those from non-energy processes) (B. P. Smith, 2008).

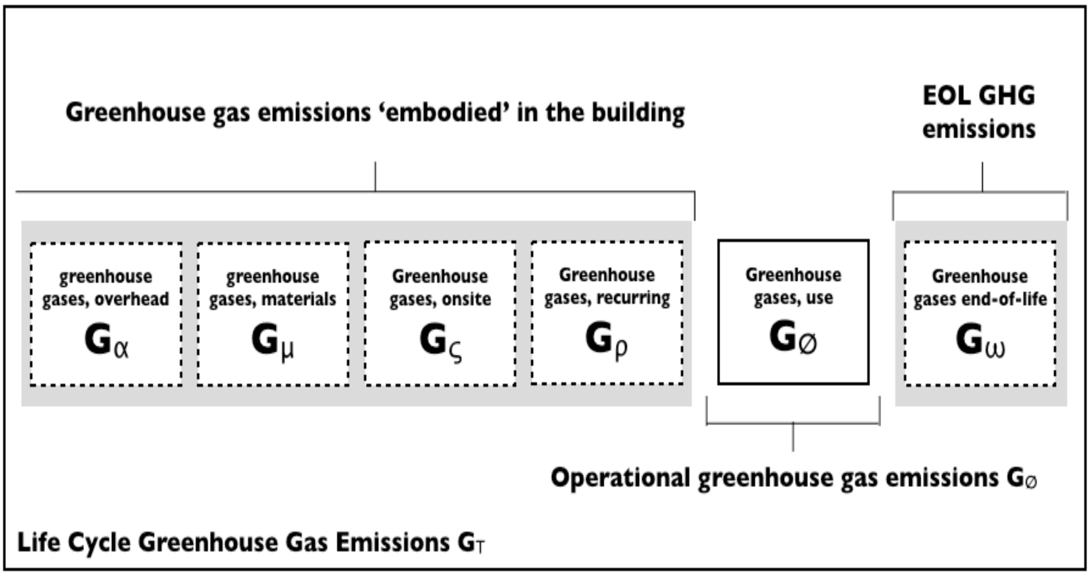


Figure 23: Overview of the constituents of a building's life cycle GHG (M. R. Fay, 1999; Hart & McKinnon, 2010; B. P. Smith, 2008).

As shown in

As shown in Figure 23 life cycle greenhouse gases components have many parallels with those of life cycle energy (and indeed life cycle costs presented on page 88); it has two principal components namely: operational ($GHG_{Ø}$) and embodied greenhouse gases (GHG_E) (Jones 2011), with end-of-life emissions making up a small proportion of the total[65]. $GHG_{Ø}$ arises from the consumption of energy and is wholly dependent on the type of energy used. In the past $GHG_{Ø}$ accounted for the vast majority of life cycle GHG of typical buildings (Lane, 2007). GHG_E emissions (and potentially credits) arise throughout a building's life and may be disaggregated into a number of sub-components (M. R. Fay, 1999; Hart &

[65] EOL GHG emissions are categorised by some as part of the embodied GHG emissions (*e.g.*, C. I. Jones, 2011, p. 5; Sturgis & Roberts, 2010, p. 10), but this is perhaps short-hand for non-operational emissions. Such usage is reflective of the importance of the dynamic between operational and non-operational emissions, and the small proportion of non-operational emissions which arise from EOL activities

McKinnon, 2010; B. P. Smith, 2008), viz., GHG Overhead from project management involved in delivering the building; Materials GHG arising from the manufacture and supply of materials and products; Onsite GHG from onsite construction and commissioning activities; Recurrent GHG from maintenance and renovation of the building; End-of-life GHG from deconstruction, recycling & disposal activities. Thus, building lifecycle GHG emissions can be disaggregated as follows:

- Operational GHG emissions – the GHG emitted as a direct result of the energy consumption during the use phase of the building;
- Non-operational GHG emissions – those emissions arising from the activities required to construct, maintain, renovate and deconstruct the building;

The non-operation GHG emissions may in turn be disaggregated into:

- GHG Overhead – emissions associated with the project management activities including those involved in delivering the building;
- Materials GHG – emissions arising from various processes involved in the manufacture and supply of materials and products for the building;
- Onsite GHG – emissions arising from the various activities and services that go into constructing and commissioning the building;
- Recurrent GHG – emissions arising from the materials, goods and activities that go into the maintenance and renovation of the building and from the management choices selected for the wastes generated during these activities;
- End-of-life GHG – net emissions resulting from deconstruction, recovery, recycling and disposal activities (including positive/negative flows) at the end of building's useful life.

Operational GHG emissions may be calculated from energy consumption data through the use of conversion factors for the particular type and source of energy – for example the grid average GHG intensity for the Irish national electricity grid in 2015 was 0.393t CO_2 per MWh (CER, 2016). Non-operational GHG on the other hand does not necessarily have a direct relationship with embodied energy as it also includes process emissions, these are particularly significant in respect of Portland cement (G. P. Hammond & Jones, 2008). The embodied GHG components can be further disaggregated (B. P. Smith, 2008; Sturgis & Roberts, 2010), resulting in an understanding of life cycle GHG emissions as described above. The life cycle greenhouse gas inventory (similar to that for costs and energy as previously discussed) may be expressed as $\boldsymbol{GHG_T} = \boldsymbol{GHG_{\emptyset}} + \boldsymbol{GHG_E}$

Relative importance of operational and non-operational GHG

Reducing GHG emissions has become a significant driver of building energy retrofit programmes and terms such as carbon savings and carbon neutrality have gained currency in energy-efficiency buildings discourse (A. Reeves, Taylor, & Fleming, 2010; Young, Perry, & Manson, 2010). As a result, measurement of an intervention's impact on GHG emissions is increasingly being added to consideration of energy and financial implications. The operational phase has historically been seen to predominate, and non-operational (principally embodied) GHG was deemed not to be a significant proportion of life cycle GHG emissions (B. P. Smith, 2008). However, the historic relationship between operational GHG and embodied GHG is changing and the relative significance of embodied carbon is increasing. New buildings are designed to be more energy efficient with ever more stringent thermal standards, and existing buildings are being upgraded to reduce their energy consumption. Furthermore the decarbonisation of electricity grids (*e.g.*, Germany's target of 80% from renewable sources by 2050 referenced by Lechtenböhmer & Luhmann, 2013) means that buildings will have less operational GHG even if no energy improvements are made *i.e.,* the same energy consumption from a build will result in lower emissions[66].

Furthermore, meeting national targets for GHG emissions reduction will require substantial reduction in GHG from centralised energy grids as these are the most realisable source of savings. For example, the UK is legally obliged to reduce its GHG emissions by at least 80% by 2050 relative to 1990 levels (UK Parliament, 2008). The UK Department of Energy and Climate produced an analysis of pathways to meet this obligation (DECC, 2010a), while it did not prescribe any particular measures, it would necessitate a significant reduction in the carbon intensity of electricity generation. Therefore, analyses that do not model such envisaged reductions in GHG emissions arising from electricity generation will likely over-estimate operational carbon. Jones (2011) estimated that the pathway analysis would require that the GHG intensity of UK electricity would reduce 95% between 2010–2050, which if achieved would mean analyses based on the status quo would be 270% over estimated as shown in Figure 24 below.

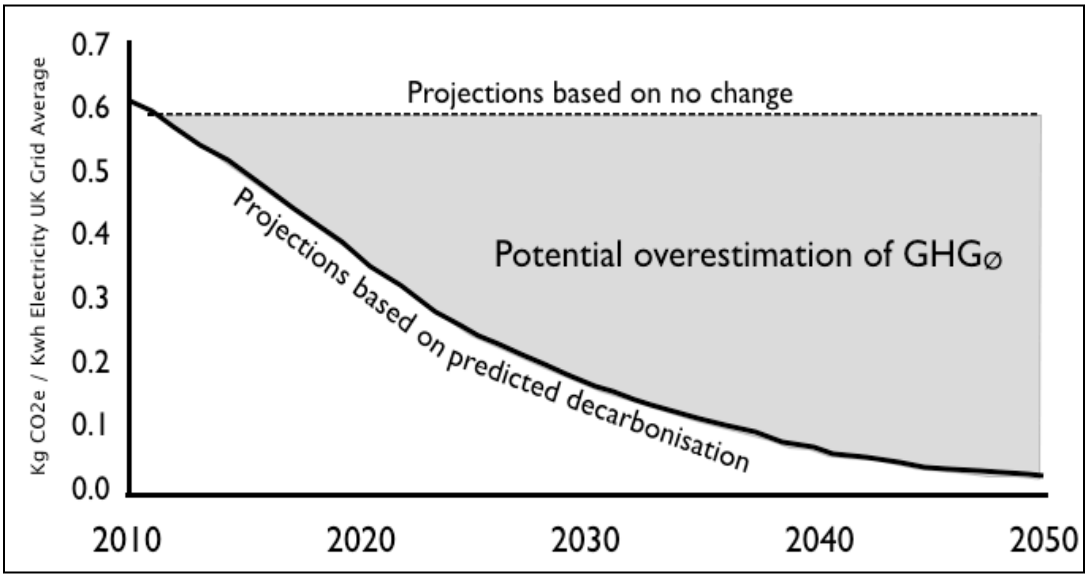


Figure 24: Overestimation of operational GHG savings due to grid decarbonisation (adapted from C. I. Jones, 2011)

These trends toward a reduced energy consumption of buildings and reduced carbon intensity of energy that will be used significantly increases the relative importance of

66 In a similar way, switching a building's sources of energy to one which is less carbon intensive (*e.g.,* from oil to natural gas) also reduces operational carbon without a decrease in energy use.

embodied GHG and its component parts *i.e.,* GHG overhead; materials GHG; onsite GHG; recurrent GHG; and end-of-life GHG. As their importance grows it becomes more important not only to consider them, but to do so in a disaggregated fashion as illustrated in Figure 23 above. This will allow the various trade-offs between the various components of embodied GHG to be considered in addition to those trade-offs between embodied and operational GHG.

3.5 Life cycle inventory methodology

3.5.1 Introduction

This thesis suggests that multi-dimensional value consideration should be incorporated in decision making on building renovation – at a minimum this should include cost, energy and GHG implications of the project(s). In such a context, there is a need for the preparation of life cycle inventories for each of these metrics. The term 'inventory' derives from the Latin inventarium, meaning "*a list of what is found*" (OUP, 2010); and this is exactly what is meant in the field of life cycle assessment (and life cycle cost analysis): the identification, quantification, and as necessary allocation, where there is more than one product, of inputs and outputs (Guinée et al., 2001). A building's GHG emissions inventory is therefore a quantification of the various gaseous emissions contributing to climate change across its life cycle. Its energy inventory is a quantification of the energy consumed across its life cycle, and its LCC inventory a quantification of construction-related and operational costs over its life.

There is great deal of diversity amongst studies purporting to take a so-called life cycle perspective on cost, energy and 'carbon' implications of new buildings and building retrofit projects. There is wide variety in the technical procedures used, temporal and physical boundaries selected, assumptions that form the basis of the studies, approaches to data quality, cut-off thresholds *etc.* Furthermore, studies often use different metrics, *e.g.*, Conventional energy analyses, (R. Fay, Treloar, & Iyer-Raniga, 2000; Scheuer, Keoleian, &

Reppe, 2003; Yung *et al.*, 2013); Emergy, *e.g.,* (Pulselli, Simoncini, & Marchettini, 2009; Pulselli *et al.*, 2007); Exergy, *e.g.,* (Shukuya, 2009); 'Carbon' Footprint, *e.g.*, (Hacker, De Saulles, Minson, & Holmes, 2008; Kneifel, 2010). Even when the metric is nominally the same, there may be significant differences, *e.g.*, energy may be on the basis of primary or delivered (secondary) fuels; carbon footprints may include a range of GHG gases or be limited to just CO_2; *etc.* It can be seen therefore that consideration of life cycle energy (or carbon) is not a straightforward undertaking. The choice of which dimension of energy to track and on which basis will depend on issues such as: the rationale for and the objectives of the study, the nature of the receiving audience, data availability, *etc.*

3.5.2 Methods

Introduction

There are a number of standards and guidance documents that could form the basis of an approach to preparing life cycle inventories for buildings. A selection of prominent examples is listed in Appendix 1. However, in recent years effort has been spent on preparing specific standards for life-cycle-oriented approaches to sustainability assessments of buildings by ISO TC 59/SC 17[67] at an international level (see Figure 25), and by CEN TC 350[68] at a European level (see Figure 26) (Balouktsi & Lützkendorf, 2016).

[67] International Standardization Organization Technical Committee 59 Buildings and civil engineering works, Sub-committee 17 – Sustainability in buildings and civil engineering works

[68] European Committee for Standardization Technical Committee 350 – Sustainability of construction works

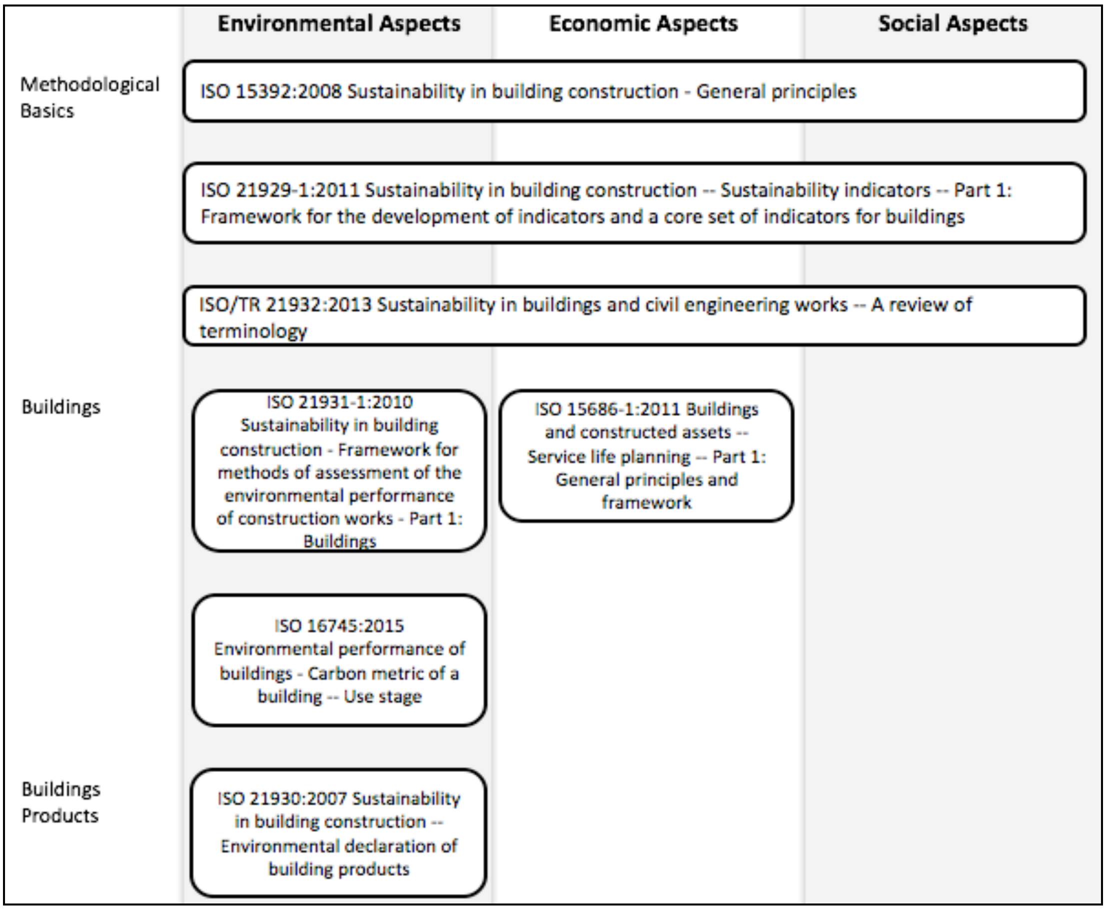


Figure 25: Standards prepared by ISO TC 59/SC 17 (derived from ISO, 2008a, p. vii)

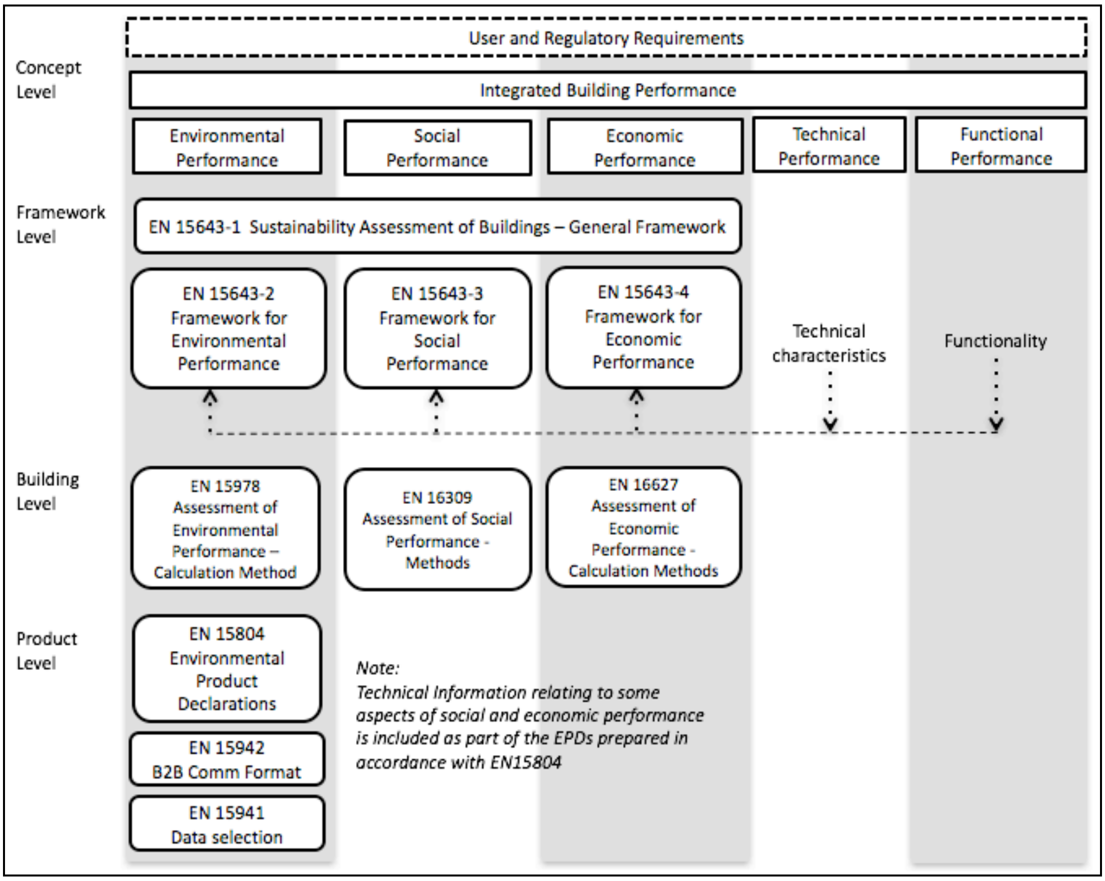


Figure 26: Work programme of CEN TC350 (derived from CEN, 2011a, p. 5)

For the purposes of produced the life inventories discussed in this thesis the European standards provide the more relevant approach. CEN TC 350 was established in 2005 with the role of developing a European harmonised, horizontal (*i.e.*, applicable to all products and building types) approach for measuring the sustainability of new and existing construction works. The CEN 350 integrated building performance mentioned in the second row of Figure 26 encompasses environmental, social and economic dimensions of performance, in addition to technical and functional performance, with which they are so interlinked (CEN, 2010, p. 5).

At the framework level, EN 15643-1:2010 provides the general systems for the sustainability assessment of buildings, establishing the principles, requirements and guidelines for the assessment of the environmental, social and economic performance (CEN, 2012a), While EN15643-2, EN15643-3, and EN15643-4, provide more specific requirements and guidelines for the assessment of each of environmental performance (CEN, 2011a), social performance (CEN, 2012a), and economic performance (CEN, 2012b) respectively.

At the building level, the relevant standards are: EN 15978:2011, which specifies the methodology and provides detailed guidance for conducting a life cycle assessment study of buildings, and therefore provides for the preparation of building-related life cycle inventories[69] (CEN, 2011b); and EN 16627:2015, which provides a calculation method for the economic performance of buildings (CEN, 2015) and so provides a structure for a life cycle cost assessment. Environmental data (and as noted in Figure 26, some social and economic data) on building products is provided for at the next level, where guidance for the preparation of environmental production declarations is included in the form of EN 15804:2012 (CEN, 2012c).

[69] As discussed on page 74, life cycle inventory studies (*e.g.,* of GHG emissions) and life cycle energy analysis may be considered as variants of life cycle assessment.

These standards can be said to comprise the normative framework for the sustainability assessment of buildings in the EU including the conduct of life cycle energy analysis and GHG emissions inventories[70] and life cycle costs analyses. Over the next three subsections, methods for the conduct of a life cycle cost analysis, preparation of a greenhouse gas emissions inventory and the determination of the life cycle energy demand of buildings are outlined and discussed.

Life cycle costing of buildings

CEN's EN 16627:2015 standard provides a calculation method for the economic performance of buildings (CEN, 2015); the system boundaries forwarded in this standard are illustrated in Figure ***27*** below. Notably the standards provides for the inclusion of site costs, although permits exclusion "*where the site has already been selected"* (CEN, 2015, p. 42) – this is in contrast with the approach previously recommended by Cuéllar-Franca & Azapagic (2014, p. 181) who purposefully excluded site costs on the basis that they were highly variable.

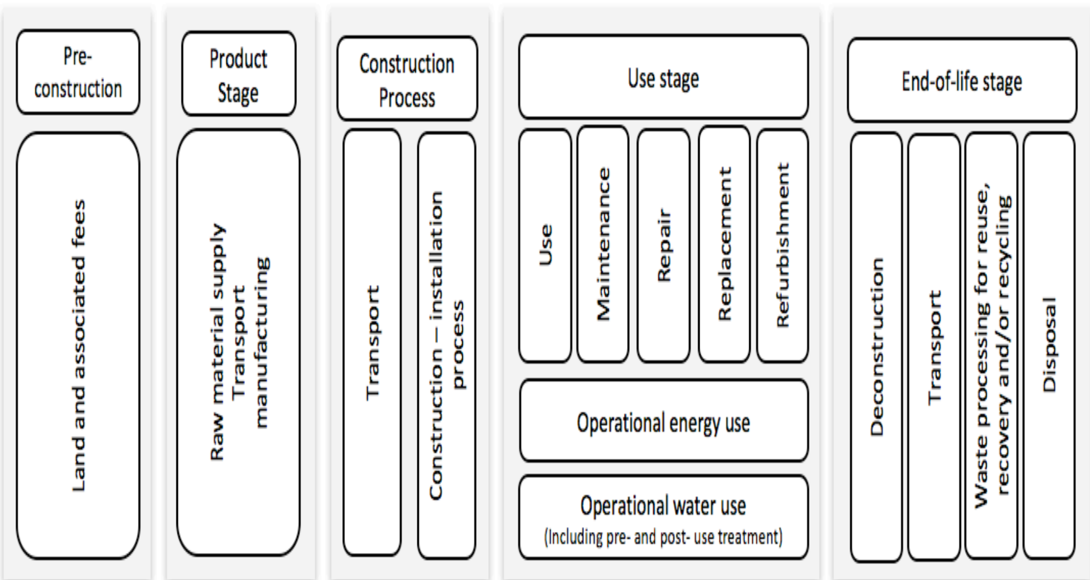


Figure** 27**: System boundaries for life costs of a building (adapted from CEN, 2015, p. 25)

The corresponding international standard ISO 15686-5:2011 takes a middle ground by suggesting that some site costs would be sunk costs by the time the life cycle costs analysis

[70] Although, Moncaster and Symons (2013) observe that while these standards have been applied for calculating environmental performance of constructed buildings, their application at feasibility stage are less clear.

is commissioned and should therefore not be included. Although it does recognise that opportunity costs of using an existing asset, such as a site could be included in the analysis, provided it is noted (ISO, 2008b, p. 18).

Following the approach of EN 16627:2015, the phases of performing a life cycle cost analysis are discussed in Section 3.6, along with the corresponding phases of conducting a life cycle energy analysis and preparing life cycle inventory of GHG emissions.

Life cycle energy analysis of buildings

Life cycle energy analysis (LCEA) is a derivative of LCA that focuses on energy consumption and offers an approach for the estimation of energy inputs to a product on a whole life basis (Menzies, Banfill, & Turan, 2007). The LCA methodologies and associated guidelines, mentioned previously, are seen as providing good structure and support for conducting an LCEA. LCA can be thought of as an easily conducted (R. Fay *et al.*, 2000) simplified, derivative form of LCA (Filimonau, Dickinson, Robbins, & Huijbregts, 2011). In this regard, Keoleian & Lewis (1997) observe that an LCEA can be considered as a part of the life cycle inventory stage of the LCA, in which the inputs and outputs, including energy are quantified. Accordingly, LCEA hearkens back to the origins of LCA, which evolved from energy analysis studies (Udo de Haes & Heijungs, 2007). Life Cycle Energy Analysis (LCEA) is used to estimate the energy consumed at each stage of the life cycle.

Menzies *et al.* (2007) observe that there are three principal alternative analysis approaches analysis approaches which can be applied to LCEA studies[71], *viz.*:

- *process analysis*, which identifies and quantifies the resource use and environmental releases from the principal production processes and some significant supplier contributions. Disadvantages of the approach include: inherent incompleteness could strongly underestimate burden;

[71] They also mention simplified approaches such as focusing on certain areas or processes of interest.

- *economic input-output analysis,* which uses input-output table which map financial flows to physical flows between economic sectors. Disadvantages of the approach include a high level of aggregation leading to uncertainty and probability of unrepresentative data;

- *hybrid analysis,* which combines the previous two approaches, some areas (often those higher in contribution, direct and first-order), are assessed by process analysis, and the remaining requirements (generally upstream contributions) are covered by input/output analysis. The disadvantage of hybrid analysis is that the process is time consuming and may lead to double counting.

Following the approach of EN 15978:2011, the phases of performing a life cycle energy analysis are discussed in Section 3.6, along with the corresponding phases of conducting a life cycle cost analysis and preparing life cycle inventory of GHG emissions.

GHG Life cycle inventory of buildings

As discussed on page 97, GHG inventories are commonly referred to as carbon footprints (B. P. Smith, 2008), and that term has become widely used in recent years – to the extent that it has not become something of a buzzword in the media, business communications and political discourse (Wiedman & Minx, 2008).

Terms such as whole life carbon or life cycle carbon have been used to apply to carbon footprints of buildings. Due to the widespread use of the term carbon footprint and its association with measurements of quite variable quality, this thesis uses the term GHG inventory to refer to determination of life cycle of GHG emissions to emphasise that use of a formal life cycle assessment methodology.

Carbon Footprints are rarely comparable due to differences in: basic concepts (Wiedman & Minx, 2008; Wright et al., 2011); methodological approach *e.g.* boundary setting (H. S. Matthews, Hendrickson, & Weber, 2008), dealing with capital goods (Finkbeiner, 2009), data temporal homogeneity (Zhai, Crowley, & Yuan, 2011), study time horizon (Levasseur, Lesage, Margni, Deschênes, & Samson, 2010), *etc.*; and the presentation and communication of results. The use of standardised approaches greatly reduces such problems, and this is particularly the case, when the standards have been designed with a specific product in mind *e.g.,* EN 16745:2015, a method for determining the operational carbon of a building (ISO, 2015).

Khasreen *et al.* (2009) observe that life cycle assessment of buildings (which by definition includes life cycle GHG determination) has become a distinct area of work within the LCA field. It would be possible to carry out a life cycle assessment (including preparing a GHG inventory) using the ISO 14040:2006 and ISO 14044:2006 standards (ISO, 2006a, 2006b), which provide guidance for generic LCA studies. However, CEN's development of EN 15978:2011, a specific standard to "*provide calculation rules for the assessment of the environmental performance of new and existing buildings*" (CEN, 2011b, p. 5) was most welcome, as it provides for greater comparisons between studies.

Following the approach of EN 15978:2011, the phases of preparing life cycle inventory of GHG emissions are discussed in Section 3.6, along with the corresponding phases of conducting a life cycle cost and life cycle energy analyses.

3.6 Inventorying life cycle costs, energy and GHG

3.6.1 Goal and scope definition

The goal of a life cycle cost analysis (LCCA) is to estimate and communicate the total costs associated with a building for a specific purpose (*e.g.*, choosing renovation options). In a similar manner, the goal of a life cycle energy analysis is to estimate and communicate the total energy consumption associated with a building, typically this would be used to select between different design options or energy conservation measures. While, the goal of a life cycle GHG analysis is to estimate and communicate the total quantity of GHG emissions associated with a building, typically this could be used for example in the selection of design options.

As with all life cycle studies a suitable scope must be established – this may include temporal, spatial and process boundaries depending. It would be expected that the same goal and scope would be decided for both the life cycle energy and greenhouse analyses, especially given that they are both components of a full life cycle inventory analysis (LCIA). Furthermore, if a multi-dimensional value analysis is the goal, considering cost along with energy and GHG implications, the scoping for all three metrics should be aligned.

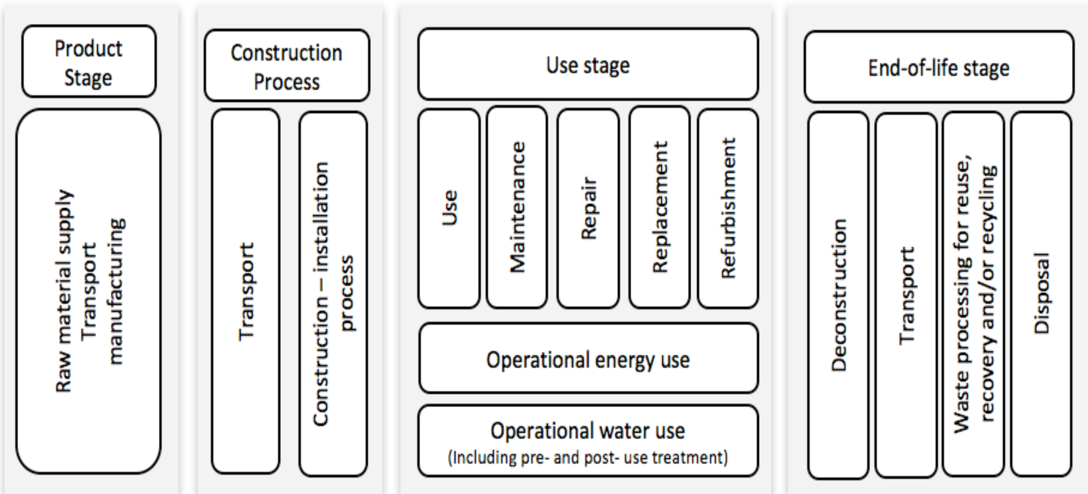


Figure 28: Scope of life cycle for multidimensional assessment of renovations

For the purposes of analysing a building energy renovation the most appropriate boundaries would appear to be four stages presented in Figure 28 above[72], which are congruent with both the approaches detailed in both the EN 16627:2015 and EN 15978:2011 standards.

3.6.2 Life cycle inventory

The life cycle inventory stage is focused on data collection. In life cycle costing (as will be made apparent by the calculation method shown on page 116) requires a number of different types of data. Kishk *et al.* (2003, *pp.* 15–19) identify five categories of data required to calculate life cycle costs of a building, namely: (i) economic variables; (ii) cost data; (iii) building use profile; (iv) physical data; and (v) performance and quality data.

[72] This is the same as figure 28 but with land costs excluded.

Table 5: Data requirements for life cycle costing

Type of data	Description	Possible source(s)
1. Economic variables	*e.g.,* discount rate, inflation estimate, cost of finance; time scale;	*e.g.,* economic projections, professional judgement (Kishk *et al.,* 2003)
2. Cost data	Initial, maintenance, refurbishment and end-of life-costs, could also include costs associated with inability to use during renovation;	*e.g.,* accounts, manufacturers, suppliers; historical maintenance data; financial projections, *etc.* (Schade, 2007)
3. Building use profile	*i.e.,* hours of use and occupancy levels, for many building types *e.g.*, hospitals, this can be a significant influence on operating costs.	*e.g.,* historical use data; operational plans
4. Physical data	Specification of building geometry, surfaces *etc.* details of heating, ventilation and air conditioning (HVAC) and related systems.	*e.g.,* building design team and associated documentation
5. Performance and quality data	*e.g.,* energy performance of the building is substantial contributor to costs	*e.g.,* modelled through whole building energy simulation such as EnergyPlus[73] *(Dunphy et al.,* 2012)

Table 5 above provides a description of these data and indicates from where they may be obtained. Although there are some life cycle cost databases, such data is inherently limited in that it is by definition, representative data and will not have the context required for detailed bespoke calculations (Kishk *et al.,* 2003, p. 19). The information required for the life cycle energy analysis and for GHG inventory is quite analogous and includes the following:

- data to calculate embodied energy / embodied carbon *e.g.,*
    - quantities and descriptions of materials and products to be used;
    - details of transport of materials to and from the site;

[73] With all the limitations inherent in energy modelling. Coakley, Raftery & Keane (2014) provide an interesting overview of approaches to reconcile model outputs with measured data

  - end-of-life management choices for wastes generated;
  - envisaged energy use by construction activities on site.

- data to calculate operational energy *e.g.,*
  - planning hours of use;
  - envisaged occupancy levels;
  - description of building (*e.g.,* specification of building geometry, surfaces *etc.*, details of heating, ventilation and air conditioning and related systems) – the more detailed the information the better the energy simulation will be.

Table 6 provides a description of these data and indicates where they may be obtained.

Table 6: Data requirements for life cycle energy and GHG inventory preparation

Type of data	**Description**	**Possible source(s)**
Embodied energy /or/ Embodied GHG emissions	Quantity of materials and products to be used	*e.g.,* building design team, suppliers *etc.*
	Embodied energy / GHG of the materials and products to be used.	*e.g.,* Environmental Product Declarations (EPD)[74]; databases such as 'Inventory of Carbon & Energy – ICE database' developed by G. P. Hammond & Jones (2008), academic publications such as Nässén, Holmberg, Wadeskog, & Nyman (2007); *etc.*
	Transportation of materials	*e.g.,* database of transport modal energy use such as ODYSSEE[75], along with estimate of distances,
	Energy consumption / GHG emissions associated with end-of-life choices	*e.g.,* LCA databases such as Ecoinvent (Wernet *et al.*, 2016); academic publications; *etc.*
	Energy used / GHG releases in construction work onsite	*e.g.,* input/output tables

[74] Such as those compliant with EN 15804:2012 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (CEN, 2012c)
[75] http://www.indicators.odyssee-mure.eu

Type of data	Description	Possible source(s)
Operational energy /or/ Operational GHG emissions	*i.e.,* hours of use and occupancy levels,	*e.g.,* historical use data; operational plans
	Specification of building geometry, surfaces *etc.* details of heating, ventilation and air conditioning (HVAC) and related systems.	*e.g.,* building design team and associated documentation
	Appropriate weather files	*e.g.,* commercial suppliers, via EnergyPlus https://energyplus.net/weather-region/europe_wmo_region_6/IRL, *etc.*
	Energy use profile	*e.g.,* modelled through whole building energy simulation such as EnergyPlus or IES-VE [76]
	Energy GHG intensity	*e.g.,* energy suppliers, LCA databases, energy forecasts, *etc.*

3.6.3 Calculations

Life cycle cost calculations

There are a number of ways of expressing the construction lifecycle cost as shown in below.

Table 7: Selected economic evaluation measures that can be used for LCC

Evaluation method	Explanation
Simple payback	Period of time required to for a project's costs to be recouped through operational savings (Schade, 2007).
Discount payback period DPP	Payback, which takes time value into account.
Net present value NPV	Expected net monetary gain or loss from a project by discounting all expected future cash inflows and outflows to the present (Gordijn, 2002).
Equivalent annual costs EAC	Related to NPV, converts all costs of an alternative to a uniform equivalent annual cost
Internal rate of return IIR	Discount cash flow measure which calculates percentage earned on capital invested in each year of the life of the project after allowing for the repayment of the sum originally invested (Kishk *et al.*, 2003).
Net savings	Difference between investment and the current value of income from project.

[76] Østergård, Jensen and Maagaard (2016) offer a comparison of building simulation software with an emphasis on early design.

Kishk *et al.,* (2003, p. 11) found "*almost all models in the literature*" use NPV, which Schade (2007) posits is the most suitable approach for construction. NPV can be calculated using the following expression (after Kishk *et al.,* 2003, p. 11).

$$NPV_i = C_{Oi} + \sum_{t=1}^{T} d\,O_{it} + \sum_{t=1}^{T} d\,M_{it} - (dRV_{iT} - dDC_{iT})$$

Equation 1

Where:

C_{Oi}	initial costs of option i
$\sum_{t=1}^{T} d\,O_{it}$	sum of discounted operational costs *at time t*
$\sum_{t=1}^{T} d\,M_{it}$	sum of discounted maintenance costs *at time t*
dRV_{iT}	discounted sale value at end of analysis period
dDC_{iT}	discounted disposal costs
T	analysis period in years

The calculated net present value of the building post renovation can then be compared to an alternative renovation option or to the status quo as shown below.

$$\Delta NPV = NPV_i - NPV_x$$

Equation 2

Where:

ΔNPV	change in net present value
NPV_i	net present value of building with energy renovation option i
NPV_x	net present value of building without intervention

Life cycle energy calculations

As discussed previously the life cycle energy of a building is a combination of that embodied in the building and that used in its operations. The embodied energy is calculated by applying energy coefficients (see Table 6 on page 114 for sources of such data) to the quantity of materials used in construction plus associated wastage. Stephan *et al.,* (2012) forwarded an methodology for calculating the initial and recurrent embodied energy of a building using of both process data and input-output data. In this approach, the embodied energy is calculated by combining the quantity of various materials (*e.g.,* kg or m^3) used with their energy coefficients (*e.g.,* GJ/kg or GJ/m^3). For those materials where coefficients are not available – these are estimates through using sector input-output data i.e., taking the total energy requirement of a construction-related sector (GJ/€) less the energy requirements of those material production processes for which data is available (GJ/€).

Combining such calculations with estimations of operational energy (*e.g.,* determined through whole building energy simulation or otherwise estimated) and end-of-life energy, provides a total life cycle energy for the building. Such an approach is readily adaptable for use for considering the life cycle energy impacts of a building renovation, by calculating the difference in life cycle energy (ΔE_T) between renovation options and the status quo. In essence, this is an estimation of the difference in avoided operational energy arising from the renovation and the embodied energy associated with the energy as summarised below.

$$\Delta E_{Ti} = E_{Ei} - E_{\emptyset\nexists i}$$

Equation 3

Where:

ΔE_{Ti} change in total life cycle energy for time period *i* resulting from renovation

E_{Ei} embodied energy associated with renovation

$E_{\emptyset\nexists i}$ operational energy avoided for time period *i* due to renovation (calculated through energy simulation or otherwise estimated)

Life cycle GHG calculations

GHG emissions associated with a building over its life cycle were previously described on page 99. For building energy retrofit projects, the 'whole life carbon' implications can be assessed on the basis of the net change of GHG emissions arising from the proposed measure (**Δ**GHG_T) in the same manner as for life cycle energy, as described in Equation 4 below.

$$\Delta GHG_{Ti} = GHG_{Ei} - GHG_{\emptyset\nexists i}$$

Equation 4

Where:

ΔGHG_{Ti}	change in life cycle greenhouse gas inventory for time period *i* resulting from renovation
GHG_{Ei}	embodied greenhouse gas associated with renovation
$GHG_{\emptyset\nexists i}$	operational greenhouse gas avoided for time period *i* due to renovation (calculated on the basis of energy simulation or otherwise estimated)

Determining GHG_{Ei} requires estimating the net embodied GHG arising from the proposed measure. This can be calculated through a cradle-to-grave life cycle analysis producing inventories of all significant GHGs (typically the Kyoto basket as described on page 99), with the process boundary set as the inputs and outputs arising from implementation of the proposed renovation.

The operational GHG emissions can be determined through whole building energy simulation using software such as EnergyPlus and applying GHG coefficients appropriate to the source of energy.

3.6.4 Interpretation

As mentioned on page 83, the interpretation stage involves the techniques to check, and evaluate information from the life cycle analyses in relation to the defined goal & scope of the study. Life cycle analyses by their nature require using various estimations, assumptions, data of variable quality and reliability. Accordingly, it is useful to conduct uncertainty, analysis which may arise as a result of a variety of causes *e.g.*, statistical variation, random errors, spatial and/or temporal variability (Heijungs & Huijbregts, 2004) and sensitivity analysis i.e., determining which data and assumptions (for instance with buildings the selected longevity of the building used for modelling has huge implications) that have most influence on results are important data quality controls (Goh & Sun, 2016).

3.7 Conclusion

This chapter reviewed the literature associated with buildings and energy, taking a life cycle view in keeping with the longevity of buildings and the nature of their use. The life cycle of a building was considered from a number of perspectives and concepts of building life cycle performance was introduced, namely energy, cost and GHG emissions. Concepts and methodologies associated with consideration of the life cycle performance of buildings were presented.

4 Value creation, delivery, and capture – a review

"Whenever you see a successful business, someone once made a courageous decision" – Peter F. Drucker

This chapter reviews the literature associated with the creation, delivery and capture of value by businesses. The review considers concepts of value, both from the perspective of the seller and from that of the consumer. The work of Lanning and Michaels (1988) and others in reimagining the traditional product focussed business strategy as one which is centre on delivering a value proposition to customers is discussed. In this context, the idea of the business model, as a statement of how businesses intend to create, deliver, and capture value, is considered in detail. The method for the literature review in this chapter followed closely that outlined for Chapter 3 on page 59.

4.1 Introduction to the chapter

While the fundamental mission of any business is to make money – the way is which it does so, is probably best conceived as providing customers with a product or service that they want (utility value) in return for a payment (monetary value). While this is a simplistic way of considering business transaction, it holds true as a general observation.

In the previous chapter, buildings were seen to be long life products with a number of cluster of activities associated with different stages of its life. Each individual activity be delivered through value chain, comprising a set of linked value-creating activities from raw material extraction through to ultimate product or service delivery (Shank, 1989).

Successful (from a multi-dimensional perspective) renovation projects require that key stakeholders are satisficed – this in turn requires that the various value chains (and the business models of the component businesses) that contribute to a project are aligned sufficiently that the objectives are compatible with that of the project.

4.2 Value concepts

4.2.1 Defining value

O'Cass & Ngo (2011, p. 646) suggest the "*… primary pursuit of any business is to understand what customers value and to create that value for them*". This begs the question as to what constitutes value. The dictionary definition of value is "*the regard that something is held to deserve; the importance, worth, or usefulness of something*" or "*the material or monetary worth of something*" (OUP, 2010). Thus, it can be seen that the concept of value is quite straightforward, while at the same time being quite subjective and rather nebulous. There is an American colloquial expression 'I know what it is when I see it'[77] and to an extent, the same can be said about value. In context of delivering a product or service, value can be thought of as a preferred combination of benefits, in whatever way they are defined, compared with the costs entailed in obtaining them (Morrissey *et al.*, 2014). In this view, "*value is determined by the utility combination of benefits delivered to a customer less the total costs of acquiring the delivered benefits*" (Walters & Lancaster, 1999, p. 643).

Bowman & Ambrosini (2000, p. 2) note "*a tendency in the literature to use the term 'value' to refer to different phenomena*"[78]. This use of language is evident for example, in Sirmon, Hitt, & Ireland (2007, p. 273) who speaking from the firm's perspective, using somewhat circular language, suggest that "*value creation begins by providing value to customers"*. While they are using the same term 'value' it is apparent they give particular focus to the seller's value. Thus, when they say "*the primary pursuit of business is to create value*" (2007, p. 273), they are actually referring to value for the firm, for Conner, to whom they attribute the view, actually said "*the ultimate purpose of any firm is to maximize profits*" (1991, p. 123).

The value placed on a product or service by a customer is inherently subjective and can be

[77] The expression was quite famously used by US Supreme Court Justice Stewart in 1964 describing his threshold test for obscenity (Gewirtz, 1996, p. 1023).

[78] It which they were specifically referring to the exchange value *i.e.,* monetary value realised by sale of a product and the use value *i.e.,* qualities of the product as perceived by the customer.

based on their "*beliefs about the goods, their needs, unique experiences, wants, wishes and expectations"* (Bowman & Ambrosini, 2000, p. 2). From an economic perspective, such perceptions, based on customers' so-called value systems[79,80], determine the marginal value component of the price i.e., the difference between the costs and the value they perceive, including values such as prestige, appearance, aesthetic or moral reasons (Neap & Celik, 1999, p. 181)[81]. Zeithaml (cited in Ravald & Grönroos, 1996, p. 22) defines customer-perceived value as the consumer's overall assessment of the utility of a product based on what is given and what is received. These perceived benefits are combination of physical, service and support attributes of a product, other perceived (tangible and intangible) quality indicators and the price paid to obtain it (Ravald & Grönroos, 1996, p. 22). Walters & Lancaster (1999, p. 644) suggest that how a statement of how firm delivers value to customers, in other words its value proposition, is important both within the company, as a means of identifying the value it is offering customers, and externally as a way to position itself and its products in customers' minds.

4.2.2 Value proposition

Value propositions establish and described how features of products and services are assembled and offered in order to meet customers' need (after Lanning & Michaels, 1988, p. 12). One of the first conceptualisations of value proposition was Lanning & Michaels (1988, p. 5). In a paper appropriately entitled 'A Business is a Value Delivery System', they posit that the formulation of a value proposition and development of a system to deliver it to customers, is behind a successful business strategy. In their approach, as illustrated in

[79] According to Rokeach (1968, p. 160), values are beliefs that "*transcendentally guide actions and judgements across specific objects and situations*"
[80] Narasimhan, Bhaskar, & Prakhya (2010) provide a good review of the concepts associated with person value systems
[81] Such theories are based on the idea of the customer making rational choices that provide maximum benefit to them. Such rational choice models are the dominant in thinking on consumer behaviour (Jackson, 2005, p. 7). However, this view of people as *homo economicus* is not without its critics and its limitations (see, *e.g.*, Jackson, 2005, *pp.* 35–42). While this debate is outside the scope of this thesis, it is useful to consider the issues particularly in the case of occupants and end-users of renovated buildings. Practice theory approaches are gaining ground with regard to everyday activities including energy-related behaviour (see *e.g.*, Røpke, 2009; Shove & Walker, 2010; Walker & Shove, 2007).

Figure 29 below, they reimagine the business system, which had traditionally been dedicated to producing and selling products, as one focused on delivering value to customers. The contrast between the two systems are made more apparent by the colour schemes which indicate the counterpart of the different components in each system – albeit that not all match exactly related.

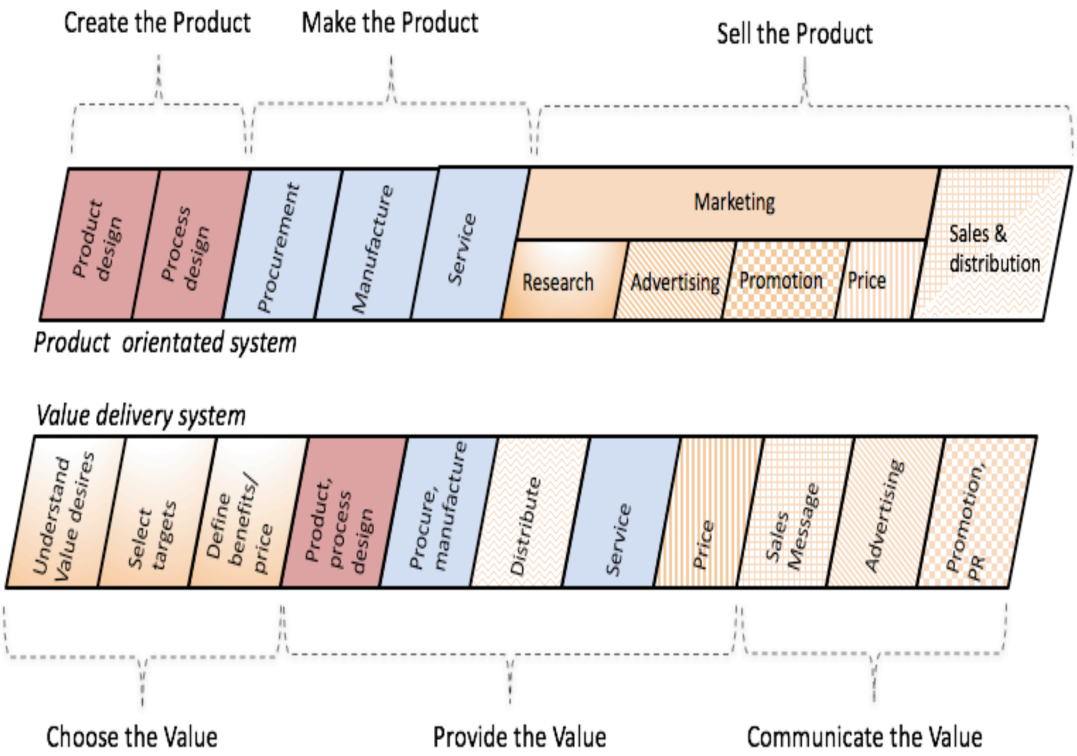


Figure 29: Product orientated system and value delivery system (derived from Lanning & Michaels, 1988, p. 12)

The most striking difference is that in the traditional product orientated system, a product was design and made and research undertaken to devise effective product positioning, pricing, promotion and marketing strategies to maximise sales to potential customers. It could almost be argued in the traditional approach products were designed and made before a full understanding of what customers wanted was identified. Lanning and Michaels' (1988) reconceptualisation of business operations as delivering value to customers, turned this approach on its head – their central thesis was that business needed to understand what prospective customers wanted before designing a product.

In Lanning & Michaels value delivery system, the first step is selection the appropriate value proposition. They acknowledge that companies often discover a successful business proposition only after the fact, but posit that "*what distinguish winners is that they do find, develop or recognise that winning proposition*" (1988, p. 5). Their approach to devising a value proposition comprises three steps: (i) analyse the market and segment by customers' desired value; (ii) evaluate opportunities in each market segment; and (iii) choose the value proposition that best address these opportunities (1988, p. 6). A checklist outlined in Table 8 below is offered as a means of selecting the most appropriate value proposition for a firm to offer.

Table 8: Value proposition checklist (derived from Lanning & Michaels, 1988, p. 10)

Clarity needed on:	**Evidence needed for:**	**Assurance needed that:**
benefits to be offered	adequate market demand	the best of several value propositions considered
prices to be charged	acceptable returns	The value proposition is clear and simple
customers to be targeted	viability in light of competition	
superiority of value proposition for target market segment	achievability *i.e.,* requiring only feasible changes in current business	

In the value delivery system model, the value proposition ideally needs to be reflected in every function of the firm[82], as illustrated in the structure of the model shown in Figure 29 on page 123. Here the traditional activities associated with product design, manufacturing, after-sales service, pricing, and distribution are each considered as components of value provision. This contrasts with the traditional perspective, where they would be considered quite separate and divided amongst the product creation, production and sales activities – as illustrated by Figure 29 on page 123.

Similarly, the consideration of value continues with the activities of crafting the sales message, advertising campaigns, promotions and general public relations. The

[82] Lanning and Michaels (1988, p. 13) observe that "*(a) value proposition may be successfully delivered without echoing through every function of the business, but the chances are improved the more that each element of the business reinforce the same objective*".

disaggregation of activities of the traditional product-centric model of a firm, and conceptualisation in terms of a system for delivery value leads to reimagining the function of activities, and their links to each other and to the overall business strategy. In this regard, market research is a particularly interesting example. Traditionally, it is fundamentally considered a marketing activity, principally influencing how a product is positioned on the marketplace – while, in the value delivery model, such knowledge of the market is instrumental in the creation of the value proposition and directly feeding into the design of product and services.

4.2.3 Delivering value

So, if it is accepted that the essential process of business is delivering value to customer, Osterwalder and Pigneur's (2010, p. 14) succinct description of business model as the "*rationale of how an organization creates, delivers, and captures value"* is particularly relevant. The following section shall explore the concept of business models, which are fundamental centred around the delivery of a value proposition to customers.

4.3 Business models

4.3.1 Background

Many authors have argued that the term 'business model' is not well understood and that the literature is inconsistent in its use (Al-Debei & Avison, 2010; Magretta, 2002; Osterwalder & Pigneur, 2002; Osterwalder, Pigneur, & Tucci, 2005; Timmers, 1998). Osterwalder and Pigneur (2002) argue that business models are the 'missing link' between the strategy of the organisation and the actual business processes of that organisation. Traditionally, strategy has attracted much attention in the literature (Chandler, 1962; Mintzberg, 1990; Porter, 1980) Similarly, at the process level, much attention has been given to Business Process Reengineering *e.g.*, Guha , Kettinger, and Teng (1993) and Enterprise Resource Planning *e.g.*, Soh, Kien, and Tay-yap (2000) but the business model has largely been ignored until comparatively recently.

The most accepted understanding of the 'business model' concept is reflected in Osterwalder's (2004) proposition that "*a business model describes the rationale of how an organisation creates, delivers and captures value"*. The concept can be used as an analytical tool to better understand how a company does business, to assist in performance assessment, management, communication, and innovation (Bocken, Short, Rana, & Evans, 2014; Osterwalder *et al.*, 2005). During the 'dot-com' era, many authors (Hayes & Finnegan, 2005; Osterwalder *et al.*, 2005; *e.g.*, Timmers, 1998; Weill & Vitale, 2001) explored issues relating to the importance of the business model and the internet economy. Recently, the concept has been applied beyond e-commerce in fields as diverse as open source software (Feller, Finnegan, & Hayes, 2008), open Innovation (Chesbrough, 2006a), 'long tail' business models (Anderson, 2006), mass collaboration (Tapscott & Williams, 2006), smart grid (Bae, Kim, & Lim, 2010) and increasingly sustainable innovation (Boons & Lüdeke-Freund, 2013).

4.3.2 Origin of the concept

Although sporadic examples of the phrase business model have existed for some time in the literature (for instance, Bellman, Clark, Malcolm, Craft, & Ricciardi, 1957; G. M. Jones, 1960), it was not until relatively recently that the term gained significant currency (Osterwalder *et al.*, 2005). This new-found interest has been linked to the development of information technology and the so-called information age and digital economy (DaSilva & Trkman, 2013). Shafer, Smith, and Linder (2005) report that this increased interest in business models arose from the practice of so-called 'dot.com' companies utilising them as a tool when pitching for funding. Indeed, so linked is the business model concept to information technology that Osterwalder, Pigneur, and Tucci (2005) note a correlation between the number of references in the literature and the NASDAQ index[83].

The advent of the Internet facilitated the development of many novel approaches to conducting business and so references within the literature to business models have been

[83] The NASDAQ Stock Market, the world's first electronic stock exchange is more heavily weighted towards technology than its peers. This emphasis was initially due to its novel use of technology, subsequently its reputation as a technology focussed market became somewhat self-fulfilling.

associated to a large extent with e-commerce (see, for instance Amit & Zott, 2001; Gebauer & Ginsburg, 2003; Gordijn, Akkermans, & van Vliet, 2000; Gordijn & Akkermans, 2003; Osterwalder, 2004; Osterwalder & Pigneur, 2002; Pijpers & Gordijn, 2007). However, this focus on information technology may serve to obscure that the business model concept is relevant to all types of businesses.

4.3.3 Defining the concept

The term 'business model' itself instinctively conveys a rudimentary understanding of its meaning, suggesting a representation of a company's dealings. However as Porter (2001) observes "*the definition of a business model is murky as best*". As mentioned above the term business model is almost defined by its ambiguity. Wirtz (2011, p. 6) noted that the tradition of business model within business management theory included a long period of conceptualisation prior to the idea of an actualised business model emerging. These differing views are still contained in the literature, indeed Osterwalder *et al.* (2005) observe a continuum of views from those that consider it a generic term to mean the way in which a company does business (*e.g.*, Gebauer & Ginsburg, 2003), to those that focus on the model aspect of the term, and use it to mean the realisation of a representation of a company's business logic (*e.g.*, Osterwalder, 2004). De Reuver, Bouwman, and Haaker (2013) point out a difference between European and American perspectives on business models, reporting that Americans focus principally on classification within specific sectors *e.g.*, Afuah & Tucci (2003) with information technology or use for open innovation as championed by Chesbrough (2003, 2006b, 2006a, 2010). Whereas the European school of business models has tended to focus on developing "*practical approaches to design and test new business models*" as exemplified by the work of Gordijn & Akkermans (2001), Bouwman, Haaker, and De Vos (2008), Osterwalder & Pigneur (2010), *etc.*

DaSilva and Trkman (2013) note the discrepancy between the importance attributed to the term and the low level of clarity of its meaning. Ghaziani and Ventresca (2005) suggest that much of this confusion arises from the ambiguous use of the term historically; the influence of changing cultural paradigms over time; and the fact that different groups of people use the term in different contexts, with research and practitioners focusing on different aspects of the concept.

This continuum of views leads to a variety of definitions of business model in the literature (see *e.g.*, Amit & Zott, 2001; Christensen, Anthony, & Rot, 2004; Osterwalder, 2004; Osterwalder *et al.*, 2005; Seddon & Lewis, 2003; Shafer *et al.*, 2005; Teece, 2010; Timmers, 1998; Tucker, 2001; Wirtz, 2011), including:

> *… architecture for the product, service and information flows, including a description of the various business actors and their roles; and a description of the potential benefits for the various business actors; and a description of the sources of revenues – Timmers (1998).*

> *… depicts the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities – Amit and Zott (2001).*

> *… description of how your company creates value for customers that in turn generated revenue and profits for your company – Tucker (2001).*

> *… abstract representation of some aspect of a firm's strategy; it outlines the essential details one needs to know to understand how a firm can successfully deliver value to its customers – Seddon and Lewis (2003).*

> *… conceptual tool that contains a set of elements and their relationships and allows expressing a company's logic of earning money. It is a description of the value a company offers to one or several segments of customers and the architecture of the firm and its network of partners for creating, marketing and delivering this value*

and relationship capital, in order to generate profitable and sustainable revenue streams – Osterwalder (2004, p. 15).

… representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network – Shafer, Smith, and Linder (2005).

Surveying the multitude of meanings assigned to the term 'business model', DaSilva and Trkman (2013) posit that it has frequently been misused by both academics and practitioners, noting that the use of the term often includes a mix of strategic, economic and revenue models. However, this perspective might be considered to reflect disciplinary bias and perhaps even be considered a rather patronising view[84]. Such a view somewhat misses the point that the term has different meanings dependent on context. In this light, Ghaziani and Ventresca's (2005) study of the changing frame and context of the term in peer reviewed journal articles over a quarter-century is very instructive. In the initial period 1975 to 1989 the vast majority of references to the term were in the context of computer/systems modelling, while during the later period 1995-2000, the plurality of frames is linked to value creation. Other frames such as conception, revenue model and e-commerce had also become more significant than computer/systems modelling during this time. This is not due to misuse of the term as DaSilva and Trkman would have it, but rather the adoption of an evolving concept by different disciplines addressing different issues.

This is substantial scope for confusion (and many examples in the literature) between the business model concept discussed above, notwithstanding its multiple personas, and the idea of the business process model. This is not helped by the frequent use of the term 'business modelling' to refer to the preparation of a business process model in addition to the concept addressed in this chapter. Gordijn *et al.* (2000) suggest that the business model and business process model concepts refer to different decisions and address the needs of

[84] Indeed, the title of the article itself 'Business model: what it is and what it is not' could almost be considered hubris by some.

different stakeholders viz., a business model illustrating the plan of how business is arranged i.e., who is creating and exchanging value, with whom and for what compensation; a business process model focusing on the operational aspects of business, the implementation of the plan i.e., what processes are to be carried out, how and by whom. They further comment that a key distinction is that business models focus on value, whereas business process models focus on how a process is to be carried out. In many respects while they are both approaches to the conceptual modelling of business, they do very different jobs addressing different needs

Wirtz (2011) distinguished three streams of research or schools of thought during the development of the business model concept, which he suggests are replicated by corresponding theoretical approaches by researchers. The first stream identified by Wirtz emerged from the information technology sector[85]. It involves the development of new ways of doing business – such new business models became popular during the dot.com boom once there was a realisation that existing approaches were not satisfactory for the opportunities emerging around the new technologies: web-based products and services. Boons & Lüdeke-Freund (2013) note substantial body of literature relating to technology and business models and suggest a possible relevance for sustainable innovation since technologies that contribute to sustainability may have similar impacts[86].

The second stream concerns organisational theory and positions the business model as a strategic management tool. In this context, the business model is used as a developmental tool to represent, plan and reorganise the architecture of a company's business systems with a view to increase organisational efficiency. The third-stream builds on this management tool, adding the element of market competition to the efficiency focus. The

[85] Worryingly, Wirtz (2011) does seem to conflate (partially at least) business model preparation and business process modelling, and while they have a shared history, their current very separate functions and identities need to be re-emphasised to avoid the confusion discussed earlier.

[86] There is a risk that such a suggestion would be interpreted as meaning that sustainable innovation always equates with novel technology, which of course is patently false, one only has to look at novel business models for an example, which in and of themselves provide potential for sustainable innovation.

basis for this third stream of business models is that creating and delivering customer value is central to a business model. Wirtz (2011) notes that in creating and developing unique value propositions for customers, business models can themselves become a competitive advantage with novel developed business models being the means by which companies execute their market strategies. Commenting on this phenomenon, Casadesus-Masanell & Ricart (2010) opine "*a business model is the direct result of strategy but is not, itself, a strategy*" describing "*a business model is a reflection of a firm's realized strategy*". A corollary of this is the strategic interaction or competition between rivals is executed through business model modifications.

4.3.4 Components of business models

For every understanding of the business model concept there are one or more ideas of which components make up the business model. Osterwalder's (2004) Business Model Ontology forwarded four pillars comprising nine components, as described below and illustrated in Figure 30.

1. Product – value proposition: overall view of a company's products and services that provide value to customers;

2. Customer interface – target customer: market segment to which a company wants to offer value; distribution channel: means of communicating with the customer; relationship: links a company establishes between itself and customers;

3. Infrastructure management – value configuration: arrangement of activities and resources required for value creation for customers; capability: ability to execute repeatable pattern of actions required for value creation for customers; partnership: voluntarily initiated cooperative agreement between two or more companies to facilitate value creation for customers;

4. Financial aspects – cost structure: representation in monetary terms of the means (to

be) employed in the business model; revenue model: way in which money is made through variety of revenue flows.

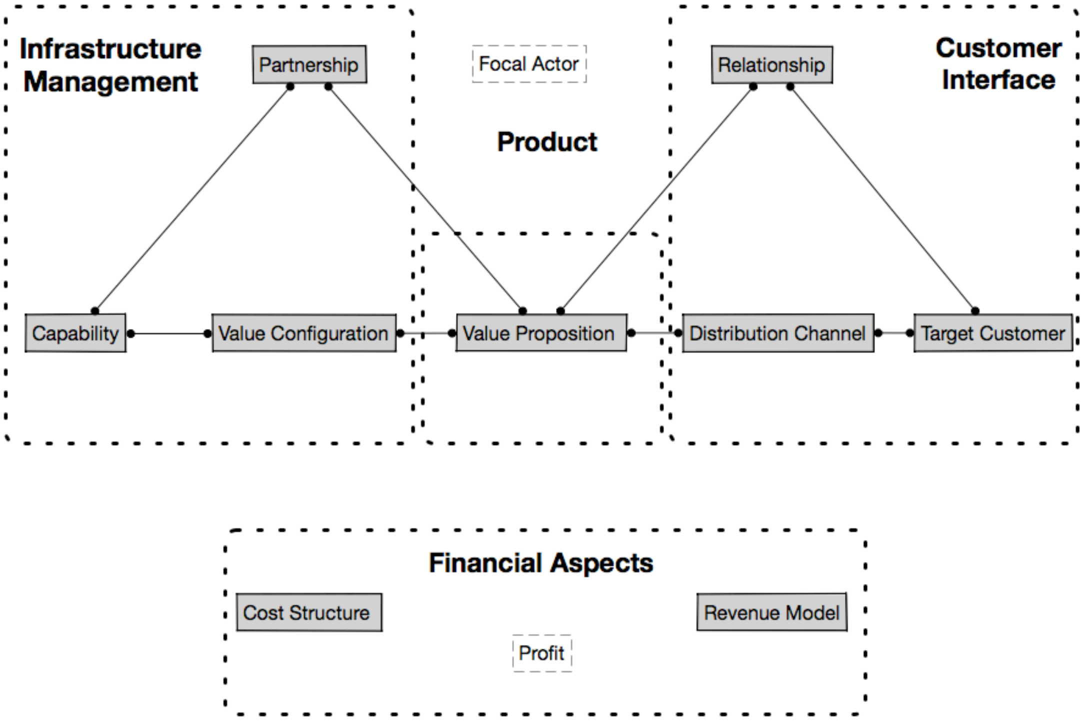


Figure 30: Components of business mode*l (adapted from Osterwalder, 2004)*

4.3.5 Towards a synthesis

Osterwalder's work – which Lambert (2006) observed drew extensively on previous research – is highly cited and widely used by practitioners (De Reuver *et al.*, 2013) (see *e.g.,* the business model canvas discussed later in this chapter). Furthermore, the model is comprehensive and reflects the elements described by other authors. Table 9 illustrates where the components described by other authors fit into Osterwalder's model, albeit not necessarily under the same name.

Table 9: Osterwalder's Business Model components compared to selected others (adapted from Osterwalder, 2004; Zott, Amit, & Massa, 2011)

	(a)	(b)			(c)			(d)	
	1. Value Proposition	2. Target Customer	3. Distribution Channel	4. Relationship	5. Value Configuration	6. Capability	7. Partnership	8. Cost Structure	9. Revenue Model
Hamel (2001)	☑	☑	☑	☑	☑	☑	☑		☑
Chesbrough & Rosenbloom (2000)	☑	☑			☑		☑	☑	
Amit & Zott (2001)	☑				☑		☑		
Applegate & Collura (2001)	☑	☑	☑	☑	☑	☑	☑		☑
Weill & Viale (2002)	☑	☑	☑			☑	☑		☑
Petrovic *et al.* (2002)	☑		☑	☑	☑	☑			☑
Gordijn (2003)	☑	☑			☑	☑		☑	☑
Magretta (2006)	☑	☑						☑	☑
Afuah & Tucci (2007)	☑	☑			☑	☑		☑	☑
Bonaccorsi *et al.* (2008)	☑	☑	☑		☑		☑	☑	☑
Brousseau & Penard (2013)	☑	☑	☑		☑	☑	☑	☑	☑
Johnson (2009)	☑	☑	☑		☑	☑	☑	☑	☑

Legend: (a) Product (b) Customer interface (c) Infrastructure Management (d) Financial Aspects

Boons & Lüdeke-Freund (2013) combined Osterwalder's work with that of Doganova & Eyquem-Renault (2009) and proffered a distillation of the models identifying the following four components of an generic business model: Value proposition: what value is embedded in the product/ service offered; Supply chain: how upstream relationships are structured and managed; Customer interface: how are downstream relationships with customers structured and managed; Financial model: costs and benefits from the first three elements and their distribution across business model stakeholders.

4.3.6 Business model canvas

Building on the ideas forwarded in his thesis (2004), Osterwalder (with Pigneur and others) further developed, refined and codified the concepts embodied in the original business model ontology. Through this work the business model canvas (Osterwalder & Pigneur, 2010)[87] was created – this is a visual chart which serves as an entrepreneurial tool facilitating the description, design, challenge, invention, and reinvention of business models. The canvas (an example is shown as Figure 31 on p. 135) includes sections for each of nine identified building blocks, which evolved somewhat from his earlier work, *viz.*,

1. Customer Segment: identification of the particular groups of customers that a company aims to serve with its value proposition (Osterwalder & Pigneur, 2010, p. 20);

2. Value Propositions: a description of the goods and services that constitute its offering for a target customer segment (ibid., p. 22);

3. Channels: description of the means by which a company communicates with and satisfies demand from its customer segments for its value propositions (ibid., p. 26);

4. Customer Relationships: an outline of the different relationships (communication, distribution, sales) a company establishes with its target customer segments (ibid., p. 28);

5. Revenue streams: a representation of the income generated from each customer segment (ibid., p. 30);

6. Key resources: detail of the most important assets (*e.g.*, production facilities, human resources) required for a company to actualise its business model (ibid., p. 34);

7. Key activities: a description of the most important things for a company to accomplish for its business model to succeed (ibid., p. 36);

8. Key Partners: detail of the network of partners and suppliers that make the business

[87] An early conception of the business model canvas was first introduced *c.* 2008 by Osterwalder through blog posts and online discussions (Martin, 2008).

model work (ibid., p. 38)[88];

9. Cost Structure: a description of the costs incurred to operate a business model (ibid., p. 40).

The narrative for these building blocks is succinctly described by Osterwalder and Pigneur (2010, *pp.* 16–17) who explain an organisation serves one or more **customer segments**, by solving customer needs with **value propositions**, which are delivered to customers through communication, distributions and sales **channels**. Throughout these interactions, **revenue streams** result from each value proposition successfully offered to customers and **customer relationships** are established and maintained. In delivering the value proposition a number of **key activities** are performed utilising **key resources** within the company and working with **key partners** through the outsourcing of certain activities and acquisition of some resources. The previous outlined elements define the **cost structure** of the business model.

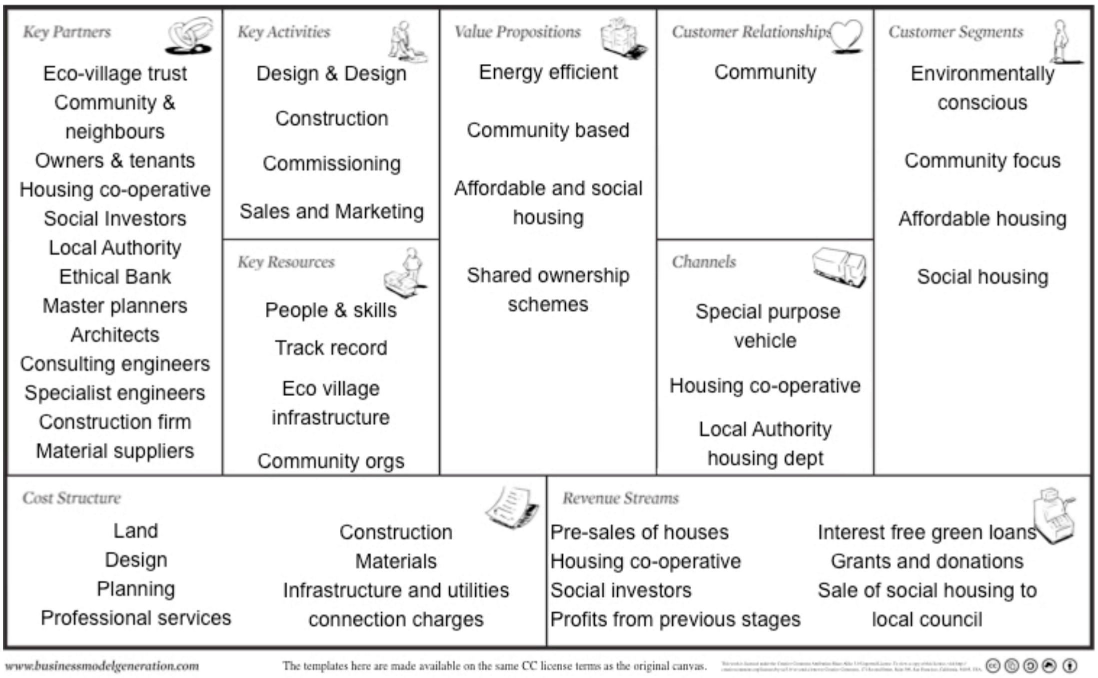


Figure 31: Example of a business model canvas for a construction project (one of the case studies used for interviews) (Adapted from Osterwalder & Pigneur, 2010, p. 46)

Figure 31 above shows an example of a business model canvas for a construction project, which formed on the case-studies used for the interviews reported in chapter 5. It is an

[88] These key partnerships form what is called a 'value network' (Chesbrough, 2007).

interesting example because of the multiple strands involved in the project including commercial sales, affordable housing and social housing. Furthermore, implementing such a project within an intentional community[89] means that there are many more stakeholders who can influence the project, resulting in a more participative approach to the planning and implementation of the project.

Osterwalder and Pigneur (2010, p. 42) consider that the business model canvas is most useful when it is put on large surface *e.g.*, plotting the canvas on a large surface such as a white board or large poster. This allows multiple people to work together, discussing the business model elements and outlining prospective components of a new model – often using tools such as post-it notes, white boards & markers, *etc.* In this way, the canvas itself becomes a collaborative tool that facilitates and promotes discussion, idea exchange, creativity, analysis and reiteration[90].

4.3.7 Business model for who?

As discussed in the previous chapter, construction projects whether they be new build or renovations are realised by a large number of actors aligned within a temporary multi-firm configuration (TMFC) with a mixture of informal and formal, bilateral and multilateral relationships (Dunphy *et al.*, 2013b). De Reuver, Bouwman, and Haaker (2013) comment that "*A strength but also a limitation of the business model canvas is that it focuses on one single company's internal business model rather than a partner network*". So, while the business model canvas has great utility the emphasis on the focal company is a hurdle[91].

Even in the case of a project related special purpose vehicle (such as that used in case study illustrated by Figure 31 above), the emphasis of the business model will be on one entity and will not reflect the interests of partners, and perhaps not even those of the companies

[89] An intentional community is where group of people come together to form a community with intent, purpose, and commitment to a mutual concern (*e.g.*, green living, spirituality, *etc.*). Such communities are designed to have a high degree of social cohesion of because of their shared values.

[9090] This approach was used, for example, to produce the business canvas shown on page 120.

[91] In the case of a project related joint venture for example, the focal company will be the joint venture entity itself.

that formed the special purpose vehicle. [92]

Recognition of external activities and stakeholders seems more evident in Doganova & Eyquem-Renault's (2009) work, which viewed business model as a market device than in Osterwalder's work, where it perhaps was seen more as internal business planning or strategy tool – of course it must be recognised that the two are not inherently incompatible, but the differing emphasis is notable. Zott and Amit (2010) are more explicit in this regard, expanding the concept of the business model to reimagine it as an activity system encompassing interdependent activities outside of the focal firm and in this way portray it as a system of interdependent activities. Such framing is of course more relevant to the delivery of energy efficiency building projects (as treated in the previous chapter) than more conventional conceptions of business models. A specified variation of the business model canvas building on the work of those who acknowledge external actors (Zott and Amit in particular) is required to further this aspect. This should in so far as possible reflect the current trends towards user centred design processes.

4.3.8 Business model for what?

Therodore Levit observed that "*People don't want to buy a quarter-inch drill. They want a quarter-inch hole"* (Christensen, Cook, & Hall, 2005) – in other words while we may perceive people as buying products, what they are actually buying is the task performed by that product. Indeed, many innovative business models explicitly reflect the reality, an excellent example of such a business model is that adopted by Jet engine manufacturers such as Rolls-Royce (Osterwalder & Pigneur, 2010, p. 24) and GE (Chesbrough, 2007) where they supply engines to airlines and service them in return for a fee per flight hour rather than outright sales[93]. In Chapter 3, the concept of functional unit *i.e.*, the "*quantified performance of a product system*" was introduced in the context of life cycle analysis (Guinée et al., 2001; ISO, 2006b). This idea is analogous to the marketing concept of

92

93 Of course, such explicit product as a service business models are not new – early steam engines were also offered on a utility-hire basis to overcome market confidence.

customers 'hiring' a product for a 'job to be done' rather than purchasing a product (Christensen *et al.*, 2005). Both concepts focus on the utility that a prospective customer obtains from the product.

Extending this approach, overt conceptualisation of the implicit services inherent in products offers advantages for developing sustainable business approaches for energy efficient building projects. Most importantly it provides a ready mechanism for aligning – in so far as appropriate – the functional unit of the renovation (for life cycle analyses), the value proposition (for business model development), and the 'job to be done' (for market positioning and communication). Considering these concepts from different domains in such homologous terms facilitates the development of business models which contribute to the life cycle optimisation of building energy renovations. In the context of building energy efficiency projects there are a plethora of actors supplying goods and services to other actors through the life cycle of the building. There is a need to define what the 'quarter-inch hole' is for such projects on a project-by-project basis, ideally this should be done at an overall project level in addition to sub-project scale. The contributions of this thesis (hubs of activity model; multi-dimensional perspective on value; life-cycle perspective on buildings and building performance) are all intended to facilitate such a consideration of value.

4.4 Value chains

Peppard & Rylander (2006, p. 131) contend that the value chain has been used since the 1960s/70s as both a concept and tool, to understand and analyse industries. Originally used to depict the development path of mineral-exporting economies (Kaplinsky, 2004, p. 181), the value chain concept has become more prominent in business management literature since the 1980s, especially following the work of Porter (1985). Kaplinsky (2001, p. 4) says the value chain concept described "*the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a* *combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use"*. This holistic view is in keeping with the lifecycle perspective previously discussed.

According to Porter and Millar (1985), the value chain[94,95] concept divides a business' activities into those "*technologically and economically distinct activities it performs to do business*" (examples of these distinct activities are shown in Figure 33 below). These so-called 'value activities' create value, for which buyers are willing to pay, quite simply, if the amount they are willing to pay excess the cost of value activities, the business is profitable. As van Renburg (2008, p. 5) puts it, "*effective value chains generate profits"*. Thus, to be effective a value chain must be competitive and should either perform the value activities at a lower cost or alternatively, command a premium price by delivering additional value through differentiation (Porter & Millar, 1985). Accordingly, value and value chain concepts provide a good framework for the analysis of company-level competitive strengths and weaknesses, whilst also allowing for analysis of the inter-company links (Dunphy *et al.*, 2013b; Morrissey *et al.*, 2014).

Value chain analysis (VCA), which is considered a core strategic management tool, is a structured method to analyse value chains by disaggregating the chain of activities into relevant segments, to gain a better understanding of the nature of the value / cost relationships (Dekker, 2003). Porter's (1985) conceptualisation of value chains, shown in Figure 32 below, consists of five primary activities, inbound logistics, operations, outbound logistics, marketing and sales, and services, in addition to support activities such as firm infrastructure, human resource management, technology development and procurement.

[94] Value stream and value stream mapping are used as synonyms for value chain and value chain analysis respectively. This 'stream' terminology arose first in the context of lean manufacturing (see Womack & Jones, 2003, *pp.* 37–49) and although value chain nomenclature has generally won out, use of value stream is not unknown in the literature (*e.g.,* Arbulu, Tommelein, Walsh, & Hershauer, 2003; H. Yu, Tweed, Al-Hussein, & Nasseri, 2009)

[95] Some (*e.g.*, Hines & Rich, 1997, p. 46 - albeit also speaking from a lean manufacturing perspective) hold that the value stream concept is more specific, focusing on 'specific product or service under consideration', whereas (in their view) value chain concept would include all a firm's activities.

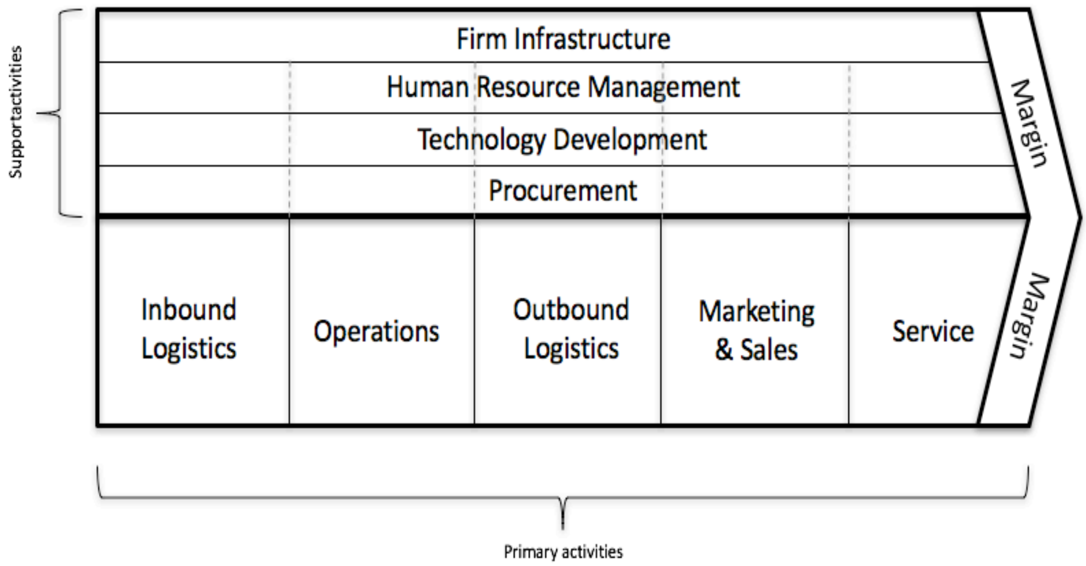


Figure 32: Generic value chain (Porter, 1985, p. 45)

Figure 33 below (derived from Porter, 1985, p. 47 figure 2-4) elaborates on the generic value chain, providing examples of value activities for a manufacturer, in this case a producers of façades. However, most of the activities are applicable for any manufacturing.

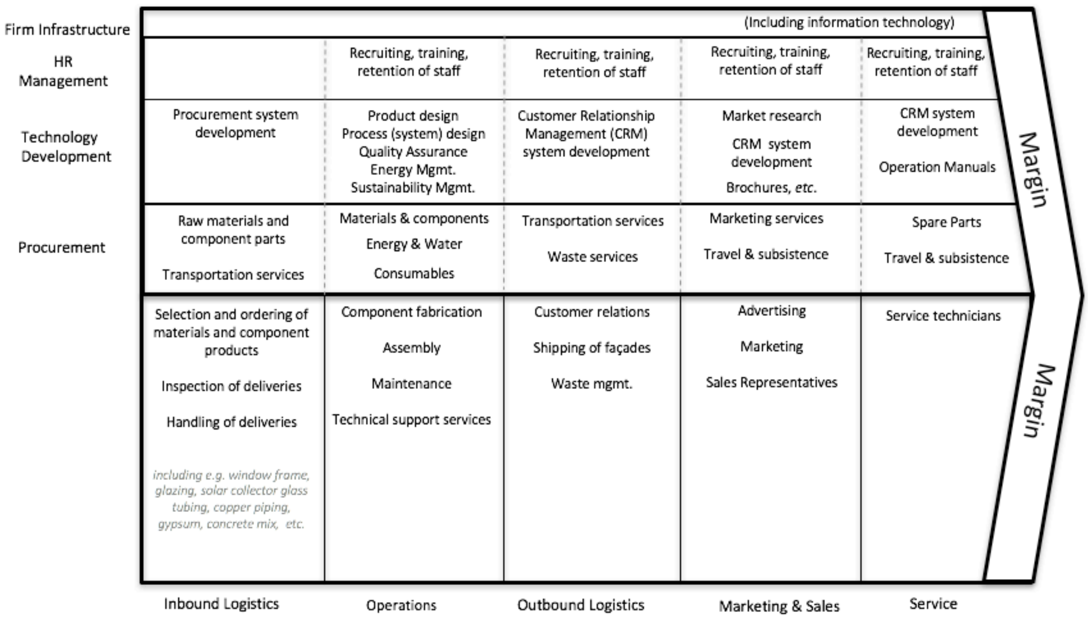


Figure 33: Value chain for manufacturer e.g., of façades (derived from Porter, 1985, p. 47)

VCA can be used as a means to both increase the efficiency of a company's internal process as well as to increase the efficiency of an industry-wide value chain (Dahlström & Ekins, 2006; Dunphy *et al.*, 2013b; Morrissey *et al.*, 2014). Other actors in a given firm's value chain also have value chains – in the above example, the manufacturers of the windows frames, concrete and so forth each have their own value chains. Suppliers' value chains create and deliver the value which is in turn fed in to the firm's value chain; the firm's product will itself become part of the buyer's value chain. These interlinked value chains form what Porter termed value systems (1985, p. 34).

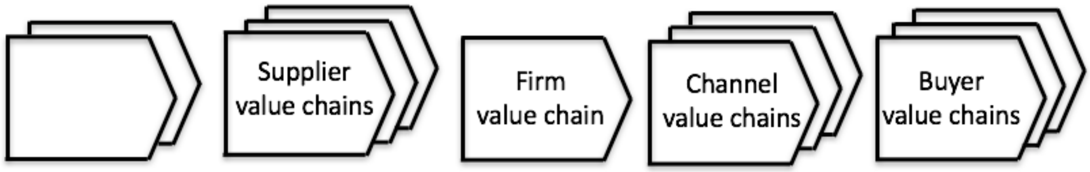


Figure 34: Linking of different companies' value chains (Porter, 1985, p. 35)

Porter's original work on VCA distinguished between those value activities which occur within a company and those that occur upstream of the company *e.g.*, raw material sourcing, or downstream *e.g.*, retailing to the final customer. He held that the appropriate level for VCA was the business unit (i.e., the activities of a firm in a particular industry) (Porter, 1985, p. 36). He retained the term value chain for the internal activities and uses value system for those external to the company. This distinction has mostly been dropped in contemporary understandings of value chain and value chain analysis[96] (Kaplinsky & Morris, 2001, *pp.* 6–7), to the extent that it is now common for value chain analysis to infer analysis of inter-firm relationships (*e.g.*, Dekker, 2003).

Pil and Holweg (2006) observe that the balance of power between suppliers and manufacturers (and this point can be extrapolated to other stakeholders) has a large effect on the way in which benefits are distributed across the value chain. Walter & Lancaster (2000, *pp.* 161–162) hold that the success of a value chain requires not only meeting customers' requirements but it is also essential that the objectives of individual stakeholders are met. They forward a new way of considering the value chain when they describe it as "*a business system which creates end-user satisfaction (i.e., value) and realises the objectives of other member stakeholders*". However, it can be seen that there is an inherent conflict between desire of the most powerful value chain members to increase

[96] Kaplinsky & Morris (2001, *pp.* 6–7) note this use of different terms has in the past been the source of confusion.

their value capture (at the expense of others) and the long-term success of the value chain.

4.5 Other conceptions of value configurations

Stabell and Fjeldstad (1998) contend that the value chain is just one possible generic value configuration, while Kähkönen and Lintukangas (2012, p. 68) argue that the "*traditional view of value creation based on value chains*" has changed and other value creating configurations, are increasingly in vogue. This has occurred in response to a realisation that the underlying value creation logic associated with the value chain concept are less applicable to certain activities, particularly with regard to services (Huemer, 2006)[97].

Stabell and Fjeldstad (1998, p. 414) forward two additional value configurations. The first, the value shop is "*where value is created by mobilizing resources and activities to resolve a particular customer problem*", which essentially describes service provision, including product-as-a-service, and other product-service systems (PSS)[98]. The second, the value network[99], also referred to as the value net, refers to "*a dynamic, flexible network comprising the relationships between its actors, in which the actors create value through collaboration by combining their unique and value-adding resources, competences and capabilities*" (Kähkönen & Lintukangas, 2012, p. 70). In contrast to the emphasis on the individual firm in the value chain, alternative value configurations, such as the value network or constellation shift the focus to the value-creation system itself, wherein different stakeholders work together to co-produce value. Moreover, "*A network perspective is increasingly necessary as few companies are involved in only one 'chain', and the conditions for efficiency in a single chain are largely determined in terms of how the activities and resources are related to those in other chains*" (Dunphy *et al.,* 2013b, p.

[97] This is particularly important, considering that many novel solutions may be offered through a product-as-a-service model (Lacy & Rutqvist, 2015).

[98] A combination of products and services in a system that provides functionality for consumers. In some definitions a balance between economic, environmental and societal aspects is assumed, while in others there is an expectation of dematerialisation (Beuren, Gitirana, Ferreira, & Miguel, 2013).

[99] Normann & Ramírez (1993) introduced the idea of a value constellation, where the focus is firmed placed on the value creation itself, with different stakeholders (*e.g.,* suppliers, partners, customers) collaborating to co-produce value. This concept is strongly linked with value network ideas, and the terms can be found used interchangeably.

650)[100].

4.6 Conclusion

Understandings of value, the value chain concept and value chain analysis have all increasingly been interpreted in a broader and more flexible manner, than envisaged by the original concept(s) (Dunphy *et al.,* 2013b). An over-emphasis on short-term gain by some stakeholders will not only impair the value proposition of other stakeholders and the overall value proposition of the value configuration itself. As previously mentioned, this risk is heightened is cases where there is a big power differential between stakeholders. This in turns leads to a lack of incentive for firms to become involved in such projects, and in fact will lead to reduced market capacity over time if not resolved. As a consequence, there is a need to develop business models for building renovation which offer adequate value for all stakeholders, that they will wish to be involved and also be sufficiently incentivised to align their objectives with that of the project.

This emphasises the need to understand the various definitions of value that stakeholder may hold in a particular project. As Dunphy *et al.* (2013b) observe "*Value for some may be lower utility and running costs, increased property value, and return on investment. For others, the definition of value may include thermal comfort, architectural aesthetics or quality of life*". Once these conceptions of value are known, a value analysis approach contribute to devising business models and project configurations in such a way such that the various stakeholders', especially those identified as occupying key roles within the value chain, capture sufficient value, in whatever way they define it, from their participation. The next chapter comprises an exploration of value creation, distribution and capture – focusing on building energy renovation projects.

[100] In this context, it is also interesting to consider the complementary idea of a 'business ecosystem' which refers to a community of companies working together to gain comparative advantages as a result of their symbiotic relationships (*e.g.,* see Barnett, 2006; Chou & Huang, 2011)

5 Understanding energy renovation project delivery

“Interviewing is not a democratic art” – Andrew O'Hagan

To better understand the composition, drivers and alternative configurations of practices, a value-based approach is applied to analyse ‘flows’ through the energy supply chain, including value, practices, norms and influences. This will be concerned with stakeholder interactions, and how key stakeholders define and disseminate ‘value’ through the energy system.

5.1 Introduction to the chapter

The work described in this chapter was conducted as part of the FP7 project UMBRELLA: Business Model Innovation for High Performance Buildings Supported by Whole Life Optimisation. The UMBRELLA project (2012-2015) was centred around the creation of new innovative business models tailored to various different stakeholders, building types, climate and policy. The business models consider split incentives of the stakeholders and policy and regulation of the building location.

The author was the UCC principal investigator on the UMBRELLA project and work package leader for the characterisation of value chains. In this respect, he was responsible for and led the work undertaken to understand the value chains associated with building energy renovations. The work described in the following chapter was undertaken by a multinational team overseen, and directed by the author. As the work is described, the actual contribution of the author to specific subtasks is made clear.

5.2 Hubs of Activity Model

5.2.1 Overview

Project delivery can really only be understood by identifying and characterising the key actors involved, which requires the characterisation of the various activities that combine to realise a project. As success in construction projects are increasingly measured through life cycle performance metrics (refer to section 3.4), a life cycle perspective on these projects and the building-related stakeholders is required. A prerequisite therefore is the definition, demarcation and description of each of the phases associated with a building's life.

To achieve this, Macmillan *et al.*'s (1999) analysis of process flow design process schematics was used as a starting point[101]. A similar approach was taken in extending this process flow to capture a life cycle perspective. This was realised through a literature review covering 20 different accounts or 'models' of a building's lifecycle. Each model was analysed, by unpacking and parsing the language used in the forwarded descriptions of activity. Similarities and differences between the descriptions of the phases of activity were explored, and a consolidated lifecycle model of activity was synthesised.

In this model, the lifecycle of a building was disaggregated to capture all the various activities which occur throughout a building's life. These activities were then clustered into six groups of related activities or Hubs of Activity, which comprise: upstream > initiation > design > construction > operation > end-of-life. These Hubs of Activity can be applied equally to a new build or a building renovation (albeit not all stages will apply in all cases – see for example Figure 35 below).

Buildings are bought and sold, renovated, upgraded, extended, and refurbished many times in their lifespan and so it can be seen that the lifecycle of a building is not a linear process. Figure 35, illustrates the complexity of a building lifecycle, showing a not atypical hypothetical scenario, which includes different occupations, changes in use, extensions, upgrades, and ownership changes.

[101] While the Macmillan *et al.*(1999) analysis focused on mapping the early stages of the design process, the approach taken was useful in considering the entire building life cycle.

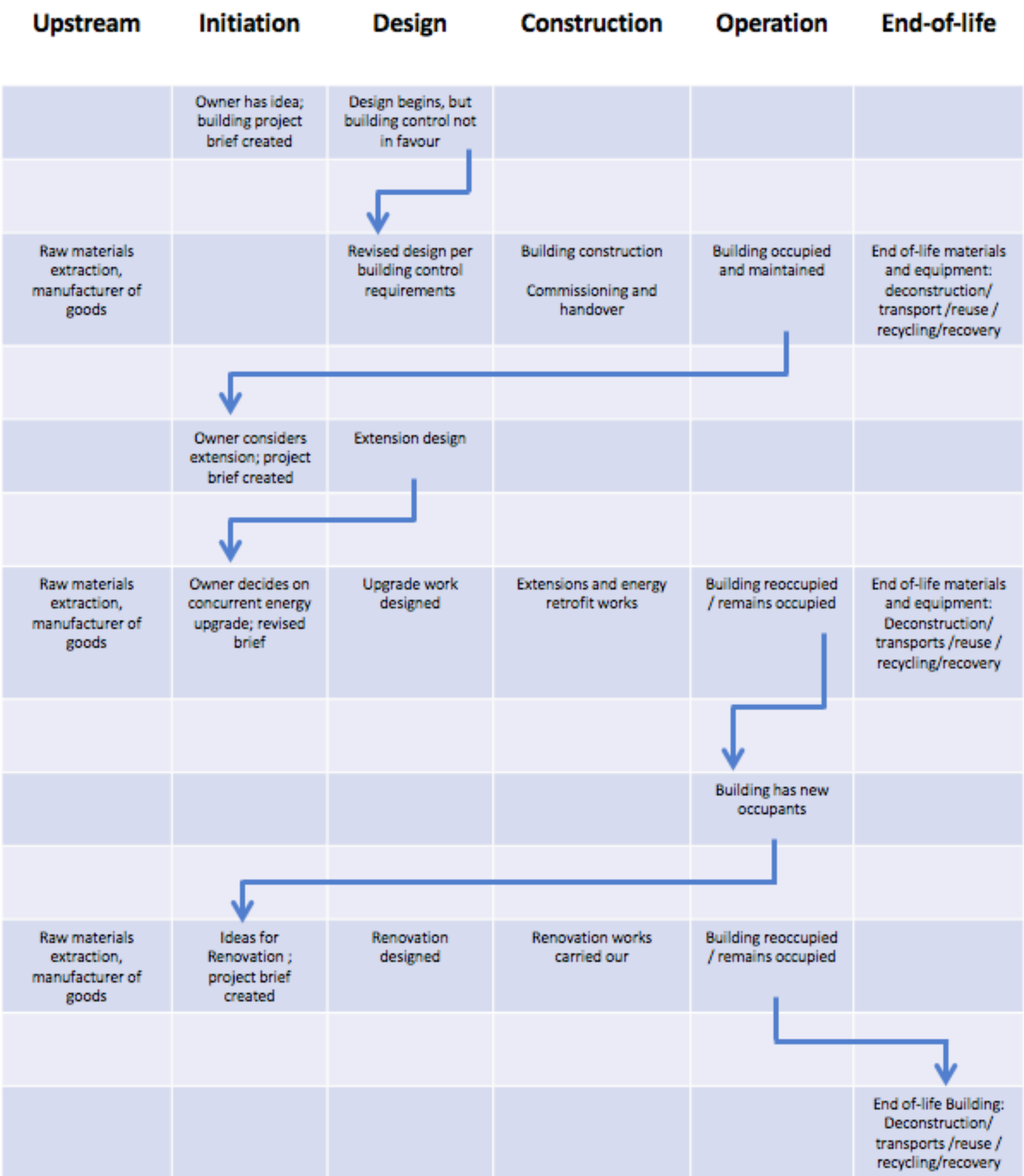


Figure 35: Examples of building's non-linear lifecycle (Dunphy *et al.*, 2013a)

It is noteworthy, that significant timespans may separate up-stream and downstream activities *e.g.*, raw materials may be extracted many years before the idea to build the build the building has even been conceived, or indeed many years after in the case of a refurbishment of an historic building. The following sections shall provide descriptions of each of the Hubs of Activity, and map the nomenclature used for phases of activity in the literature to corresponding Hubs.

5.2.2 Upstream

Upstream activities are those that occur before the construction, and which ensure the construction phase is provided with the materials, energy, equipment, *etc.* required to realise the project. The scale of upstream activities associated with any given construction project can be quite significant – a great deal of raw materials need to be extracted, processed and manufactured into products, with all the associated inputs and outputs, to deliver such projects. In addition, the transportation, warehousing and associated logistics can represent significant activity and inputs of resources (Sarker, Egbelu, Liao, & Yu, 2012). Table 10 below maps building life cycle stages found in the literature to upstream activities.

Table 10: Mapping building life cycle model stages to 'upstream activities'

Terms used related to upstream activities
Building materials manufacturing (AIA, 2010; Seo & Hwang, 2001)
Resource extraction, product manufacturing (Meil, Lucuik, O Connor, & Dangerfield, 2006)
Raw materials acquisition (Hoff, 2007; Ireland, 2008; Sobotka & Rolak, 2009)
Manufacture (Hoff, 2007; Ireland, 2008)
Production of products & components (Allione, 2007; Sobotka & Rolak, 2009)
Pre-production (Allione, 2007)
Raw materials manufacture / production (Han & Srebric, 2011)
(Manufacturer of) Materials (Ochsendorf *et al.,* 2011)
Production (of materials) (HIA, 2011)
Product (manufacturing) stage (CEN, 2011b, 2012c)

Material selection decisions can be seen to have significant impact of lifecycle performance metrics of building, and these decisions 'lock-in' substantial life cycle cost, energy, and GHG implications. Selection of materials will be influenced by a variety of factors, some of which may be unacknowledged, including regulatory requirements, project design specifications, standards, economic considerations, prior experience, peer recommendations, *etc.* Knoeri, Binder, & Althaus (2011) report that recommendations or specifications from previous stakeholders (*e.g.*, architects accepting an engineers' recommendations) in what they term interaction criterion[102] is one of the most important criteria in each material decision, with the initial project specification having less influence (particularly for structural engineers

[102] The one exception was found to be the structural engineers' design specifications which are mainly determined by law, standards and experience.

and architects) (Dunphy *et al.*, 2013a).

5.2.3 Initiation

The initiation phase is by definition centred on the project promoter, usually the owner of the building or proposed building. The owner entity may take one of any number of forms *e.g.*, individual or a large corporation, a private business or a state body, a non-profit voluntary organisation or a stock exchange listed company – in short it can be any legal entity. The owners, supported by advisors will typically (although not always) be the source of the original idea to build or renovate a property; it is they who would make the decision on the viability of the project and it is they who will initiate the project (Dunphy *et al.*, 2013a).

Table 11: Mapping building life cycle model stages to 'initiation activities'

Terms used related to initiation activities
Pre-project planning (Matar, Georgy, & Ibrahim, 2008)
Planning and clarification of task (Pahl & Bietz 1988, in Macmillan *et al.,* 1999)
Preparation of brief (Gibberd, 2001; RIBA, 2008; Zavadskas, Kaklauskas, & Banaitis, 2011)
Strategic definition (RIBA, 2008; Watson & Jones, 2005)
Site analysis, Target setting (Gibberd, 2001)
Inception (BAA project process, 1995 & UK MoD, 1997 in Macmillan *et al.,* 1999)
Demonstration need, Conception of need, Outline feasibility, Substantive feasibility and outline financial authority (Kagioglou, Cooper, Aouad, & Sexton, 2000)
Feasibility and briefing (CIRIA, 1995 in Macmillan *et al.,* 1999)
Feasibility (BS 7000 in Macmillan *et al.,* 1999)
Definition and qualification (UK MoD, 1997, in Macmillan *et al.,* 1999)
Elaboration (analysis) of assigned problem (Hubka, 1982 and French, 1971, in Macmillan *et al.,* 1999)

Table 11 above maps building life cycle stages found in the literature to these initiation activities. In this phase, owners typically have dominant power and authority over the project, as they incur the greatest risk, and have the greatest stake in the building. Owner-stakeholders[103] may have been influenced or inspired to start the project for various

[103] Within owner organisations there may be a large number of individual actors, with different levels of support for a specific project concept – some of whom may be very supportive while others may

reasons, and will interact with other stakeholder groups during this stage – the level of interaction will depend on both the nature of the owner and the nature of the proposed project. A key output of this phase is the client's brief for the project, *i.e.*, a statement of requirements.

Financial resources will be required to carry out the project. In some cases, this may be available from the owner's own resources, however in most cases external funding will be required. External funding inherently means a dilution of the power and authority of the owners over the project. This funding may take variable forms and come with various restraints and obligations, *e.g.*,

- Outside investment introduces new individuals to the ownership group, who will desire varying level of active involvement in the project. Many investors may only be interested in the final outcome of a project, while others will require regular progress reports and perhaps even active involvement in the project. All investment will result in a reduction in control for the original owners, albeit the dilution of power will vary greatly from one investment agreement to another;

- While financial institutions providing loan-finance are not likely to want to play an active role in the project or in many case to receive detailed progress reports, loan agreement conditions will introduce constraints on decision-making;

- Financial support programmes will have specific conditions, which must be met, and so grant providers may demand more regular and more detailed reporting to confirm adherence. Although the level of monitoring will depend on the size of the grant and the objectives of the support programme;

have negative views. Such stakeholders may not be able to stop the project going ahead at this stage, but they may attempt to undermine the project at later stages.

- Funding may also be provided through donations typically in the case of public and/or social buildings. While such gifts are generally seen to result in less loss of control (albeit they may come with some conditions), on occasion it may be the donation itself that led to the initial concept for the project. Similar to grant funding the level of monitoring will depend on the size of the donation and the (implicit and explicit) objectives of the donor.

Whether external funding is required or not, the financial viability of the project will need to be determined, and various costings and financial projections will be required, including: bills of quantities (BOQ), cost benefit analysis (CBA), life cycle costing (LCC), *etc.* These assessments require the services of various professionals (including architects, engineers, quantity surveyors, accountants) to estimate the cost, and make the financial case for the proposed project. These professionals may not have high levels of power, but will have substantial influence on the initiation of the project due to the data and information they gather, the interpretations they provide and the recommendations they may make (Dunphy *et al.,* 2013a).

5.2.4 Design

Once the project has been initiated the next phase of activities are those associated with the design and planning of the building (or renovation), these would include designs, building plans, project plans, *etc.* The first task will be the development of concept scheme designs. In smaller projects, designers (architects and/or engineers) will be retained to interpret the client's brief and usually will follow the project through to completion. Table 12 below maps building life cycle stages found in the literature to these design and planning activities.

Table 12: Mapping building life cycle model stages to 'design activities'

Terms used related to design activities
Design (AIA, 2010; Han & Srebric, 2011; Matar *et al.,* 2008; Watson & Jones, 2005)

Terms used related to design activities
Concept / conceptual design (Gibberd, 2001; BS7000, Pahl & Bietz, 1988, UK MoD, 1997, Hubka, 1982, and French, 1971, in Macmillan *et al.,* 1999; RIBA, 2008)
Outline/full conceptual design (Kagioglou *et al.,* 2000)
Developed design, Technical design, Fabricated design (RIBA, 2008)
Detailed design / detailing (Gibberd, 2001; BS7000, Pahl & Bietz, 1988, UK MoD, 1997, and French, 1971, in Macmillan *et al.,* 1999; Watson & Jones, 2005)
Product Stage (CEN, 2011b, 2012c),
Coordinated design (BAA project process in Macmillan *et al.,* 1999)
Coordinated design, procurement and full financial authority (Kagioglou *et al.,* 2000)
Scheme design (CIRIA, 1995 in Macmillan *et al.,* 1999)
Embodiment design (BS7000:1989, and Pahl & Bietz, 1988 in Macmillan *et al.,* 1999)
Design for manufacture (BS 7000:1989 in Macmillan *et al.,* 1999)

In larger projects an architectural competition[104] may be held, with the winning designers being offered the design contract for the project. During the design process, the architect manages the intangible attributes on which different actors will place different values – the architect is the carrier of the clients' value (Erikshammar, Anders Björnfot, Gardelli, & Björnfot, 2010). Different buildings will require different types of designers, but generally the disciplines involved are architectural (*e.g.,* architects, technicians, landscape), engineers (*e.g.,* civil, structural, mechanical, electrical), specialists (*e.g.,* sound, lighting, environmental), and certification assessors (*e.g.,* BREEAM, DGNB, HQE, LEED). Each of these will have different priorities and likely have different measures of 'success' – it is important therefore that their activities be coordinated and aligned with the overall project objectives in so far as possible.

5.2.5 Construction

The construction activities are those most readily associated with a building project comprising all those site works and support activities that realise the building works. Table 13 below maps building life cycle stages found in the literature to these construction activities.

[104] This is usually done at significant cost to the design team, but the benefits of being awarded the contract, and the associated prestige is usually sufficient motive to assume the risk.

Table 13: Mapping building life cycle model stages to 'construction activities'

Terms used related to construction activities
Construction (*e.g.*, Banaitiene, Banaitis, Kaklauskas, & Zavadskas, 2008; Gibberd, 2001; Matar *et al.,* 2008; Seo & Hwang, 2001)
On-site construction (Meil *et al.,* 2006)
Construction process (CEN, 2011b, 2012c)
Installation (Ireland, 2008)
Construction of the building (Allione, 2007; Sobotka & Rolak, 2009)
Transportation and installation (Han & Srebric, 2011)
Delivery (Watson & Jones, 2005)
Handover (Gibberd, 2001)

Construction inherently involves various types of resources, including labour, equipment and materials, the of use which necessitates procurement, logistics and many other associated aspects operational scheduling (Sarker *et al.*, 2012). The importance of project management can be seen here. However, construction is a complex operation and the planning and management of a construction project is not a simple undertaking. Bertelsen (2002) for example posits that the complexity of the whole construction "*makes any long-term predictions about the execution of the work next to impossible*", although he also acknowledge that this complexity can be reduced, for example through lean management approaches (as discussed by Bertelsen, 2004). This complexity can often lead to a reactive rather than a proactive project management, Miyagawa (1997), for example, observes that project managers seem to spend large amounts of time 'fighting fires' and rather less time implementing a plan. Project managers may be appointed from within the owner's organisation, or may be hired in externally for the duration of the project. The project manager may mange the entire project until the building is completed and handed over, but also less commonly, may be responsible for particular phases.

Construction activities are delivered by contractors (and sub-contractors) through the provision of labour and equipment onsite. However, in the vast majority of cases these contractors will also be concurrently involved in other construction projects. It is natural and logical (from the contractors' perspective) that they share their human and equipment resources across these projects, Bertelsen (2002) observes that this in effect results in the formation of a virtual network across project boundaries and potentially links into the entire construction sector in a region or even a country. This sharing of resources will lead to conflict of interest and in the words of Formentini & Romano (2011) "*could lead to an ongoing game of negotiations concerning access to available resources and the allocation of certain individuals to specific projects*". This interrelated nature of projects could also result in delays in one project being spread to others. It is imperative that contingencies for such conflicts of interest be built into project planning (Dunphy *et al.*, 2013a).

5.2.6 Operation

As discussed in chapter 3, the embodied impacts of a building are growing in relative importance vis-à-vis operational impacts. However, the costs, energy consumption and related GHG emissions assumed with the use and upkeep of a building remain a substantial (and in many case the dominant) proportion of lifecycle totals. Table 14 below maps building life cycle stages found in the literature to operation activities.

Table 14: Mapping building life cycle model stages to 'operation activities'

Terms used related to operation activities
Operation (Gibberd, 2001; HIA, 2011; Seo & Hwang, 2001)
Maintenance and replacement (Meil *et al.,* 2006)
Start-up (Matar *et al.,* 2008)
Use (CEN, 2011b, 2012c; Han & Srebric, 2011; Ireland, 2008; Ochsendorf *et al.,* 2011; RIBA, 2008; Sobotka & Rolak, 2009)
Utilisation (Zavadskas *et al.,* 2011)
Maintenance (HIA, 2011; Ochsendorf *et al.,* 2011; Zavadskas *et al.,* 2011)
Facilities management (Banaitiene *et al.,* 2008; Zavadskas *et al.,* 2011)
Use and maintenance (AIA, 2010)
Building component lifespan (Allione, 2007)
Use / reuse / maintenance (Hoff, 2007)

Occupants and other end-users are particularly important when it comes to the operational energy use of a building (Mlecnik *et al.*, 2012) – in the words of Janda (2011) "*buildings don't use energy, people do"*. Thus building energy performance analysis not only requires data about the building's physical characteristics but significantly also about its occupancy and energy-use profiles (Wan & Yik, 2004). The centrality of occupant behaviour is highlighted by Stephenson *et al.*'s (2010, p. 6123) observation of the "*surprising variability in energy-related behaviour, even across households or firms with apparently similar characteristics*". Moreover as Mlecnik *et al.* (2012, p. 471) note end-users are significant stakeholders in this regard, acting as "*multipliers and often act as peer-to-peer 'experience' experts for the acceptance or disapproval of advanced energy concepts*".

Increasingly, energy-related behaviour change is coming into vogue and facility managers, energy utilities and public agencies have employed a range of behavioural strategies to curb demand, including information campaigns on energy conservation and educational programmes to assist people make resource-efficient decisions (Strengers, 2012). Traditionally, occupants and end users are not involved in the design process for energy renovation and when they are considered, it is often as another calculation variable or as an inhibition to performance. Such views lead to building interventions that (i) very often do not suit the occupants or the way they live their lives, or (ii) which are used incorrectly[105], leading to substantial performance gaps. For these reasons, early and meaningful occupant and other end-user involvement in the design process is most desirable (Ferrando *et al.*, 2016).

5.2.7 End of life

The sixth Hub of Activity comprises those activities associated with the end-of-life of the building (or part of the building). Often disregarded, these have a not insignificant contribution to lifecycle performance. Such activities, depending on the nature (and the condition) of the building include: deconstruction, demolition, material recovery, recycling, disposal, site remediation, *etc.* Costs, energy consumption and GHG emissions associated with end-of-life activities will be dependent on the recovery, recycling and disposal (RRD)

[105] It is quite usual for the former to be ascribed to the latter and thus absolving designers of responsibility for any performance gaps

routes selected, which in turn will be strongly influenced by material selection at the at the start of the lifecycle. Table 15 below maps the building life cycle stages found in the literature to these end-of-life activities.

Table 15: Mapping building life cycle model stages to 'end of life activities'

Terms used in models related to end-of-life activities
Demolition (Banaitiene *et al.,* 2008; Seo & Hwang, 2001; Sobotka & Rolak, 2009; Zavadskas *et al.,* 2011)
End-of-life (AIA, 2010; Han & Srebric, 2011; HIA, 2011; Meil *et al.,* 2006; Ochsendorf *et al.,* 2011)
End-of-life of building and its elements (Allione, 2007)
Deconstruction (Watson & Jones, 2005)
Recycling & waste management (Han & Srebric, 2011; Hoff, 2007; Ireland, 2008)
Reuse & recycle (Gibberd, 2001)
Benefits & loads (CEN, 2011b, 2012c)

As discussed on page 76, end-of-life activities can be very energy intensive and accordingly may have a large amount of associated GHG emissions (Dixit *et al.,* 2013). There is significant interplay between phases of energy use and GHG emissions (*i.e.,* embodied v operating) this can be significant in building energy renovation planning (Ramesh *et al.,* 2010)[106]. Construction and demolition (C&D) waste presently constitute the largest waste fraction in industrialised countries, and is expected to increase in relative and absolute terms in the future (Knoeri *et al.,* 2011). C&D waste not only reflects depletion of mineral resources but also represents a substantial quantum of embodied energy consumption and GHG emissions. Peris Mora (2007) argues that the possibility of reusing by either recycling or recovering materials or energy should also be taken into account at the earliest design stages.

Yuan (2013) comments that effective C&D waste management is indispensable to the attainment of sustainable construction. The polluter-pays-principle provides financial incentive to minimise C&D waste generation by promoting the sorting, reuse and recycling

[106] When improving the energy performance of buildings, extra materials and components are applied, resulting in a higher embodied energy and GHG.

of such waste (A. T. W. Yu *et al.*, 2013); while enforcement of regulatory controls also promotes such waste management practices (Yuan, 2013). However, responding to C&D waste does not necessarily mean minimising the flow of materials by increasing recyclability or extending product lifespan. Indeed, this could even be counterproductive *e.g.*, if the alterative manufacturing resulted in increased energy consumption or GHG emissions or if the product durability comes at the cost of lower material value for post-use reprocessing (Braungart, McDonough, & Bollinger, 2007). Instead, Braungart *et al.* (2007) posit there is a need to develop "*cyclical, cradle-to-cradle 'metabolisms' that enable materials to maintain their status as resources*" and accumulate value over time – so called 'up-cycling'[107,108]. However, the development of such cradle-to-cradle (C2C) approaches for the built environment is challenging, given the longevity and complex nature of buildings and there is further work required before C2C theory is operationalised for use in the construction domain (Kausch & Klosterhaus, 2016; van Dijk, Tenpierik, & van den Dobbelsteen, 2014). Moreover, while the philosophy behind C2C offers a worthy theoretical eco-effective innovative holistic approach, the results of its implementation in practice does not match the vision, instead as Toxopeus, De Koeijer, & Meij (2015) observe it "*in practice often turns out to be merely efficient*". That is not to say that such life cycle thinking should not be implemented on buildings, rather it highlights the difficulties in doing so for such long lived complex products.

5.2.8 Conclusion

A lifecycle Hubs of Activity model was developed to provide an analytical framework for the analysis of stakeholder interactions and value flows in building energy renovations. As mentioned on page 144, descriptions of lifecycle stages were collated from the academic literature. Sources from a broad variety of fields were used, including from architecture,

[107] "Cradle to Cradle is a development paradigm with a focus on eco-effectiveness; improving the 'positive footprint' in contrast to the more conventional eco-efficient approaches; reducing the 'negative footprint'" (Toxopeus et al., 2015, p. 384)

[108] Interestingly, cradle-to-cradle is a trademark of McDonough Braungart Design Chemistry, LCC, the principals of which originated the concept. They have developed an associated detailed certification framework, which notably excludes buildings (Kausch & Klosterhaus, 2016).

engineering and manufacturing sources, to account for a range of interpretations and conceptualisations across disciplinary boundaries. It is noteworthy that each source omitted at least one key lifecycle stage, depending on their individual focus.

The Hubs of Activity model discussed in the previous sections and summarised in Figure 36 below provides the basis of an understanding of the construction marketplace that allows for an analysis of stakeholder relationships, power flows, drivers, conflicts, and potential synergies in building energy renovation projects (Dunphy *et al.*, 2013b).

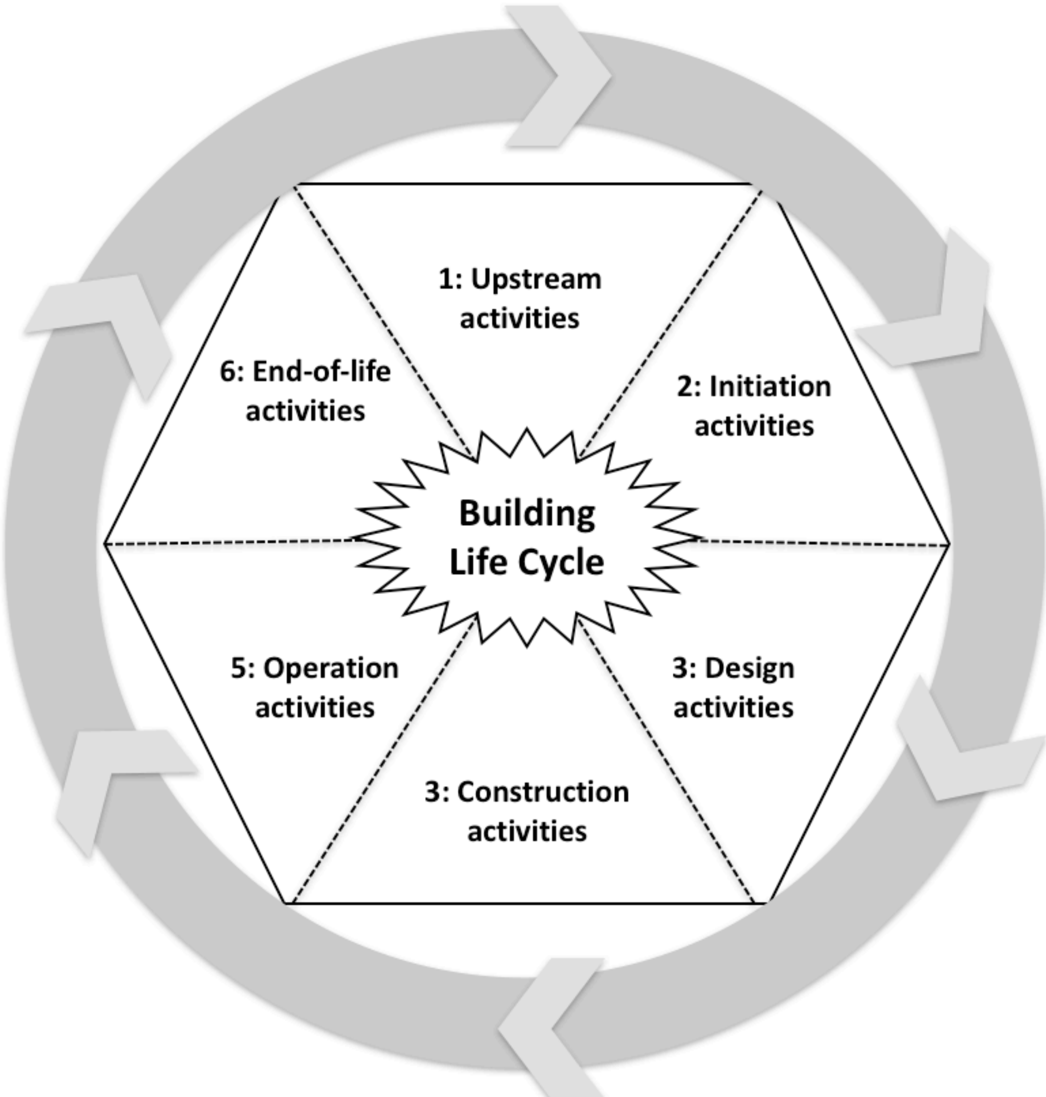


Figure 36: Hubs of Activity model of lifecycle of buildings (after Dunphy *et al.*, 2013a)

5.3 Interviews

5.3.1 Identification of interviewees

The stakeholder engagement process was carried out in eight EU member states, *viz.*, Denmark, France, Germany, Ireland, Italy, Spain, Sweden and the United Kingdom. Potential interviewees were identified through a structured process building on the Hubs of Activity model and the categories of stakeholders identified as being associated with each hub. An illustrative list of stakeholders associated with each hub is presented as Table 16 below to show the range and type of stakeholders involved in each hub.

Table 16: *Typical stakeholders associated with Hubs of Activities* (Dunphy *et al.,* 2013b).

Hub of Activity	Key Stakeholders	Other Stakeholders
1: Upstream	Manufacturers; Policy Makers; Legislators; Statutory Regulators; Investors	Primary Producers; Material Processors; Investors; Banks *etc.*; Standard Bodies; R&D Institutions; Retailers & distributors; Logistics; End-users[109].
2: Initiation	Owners; Investors; Solution Providers; Designers	Occupants / Tenants; End-users; NGOs; Neighbours; Municipalities; Insurance Companies; Investors; Utility Companies; Banks *etc.*; Policy Makers, Legislators; Public
3: Design	Designers; Owners; Project Managers; Investors; Solution Providers; Planning Authorities; Building control	Occupants; Public; NGOs; Neighbours; Banks/Financiers; Third Party Product Certification; Infrastructure providers / Utility companies
4: Construction	Designers; Owners; Project Managers; Neighbours; Solution Providers	Occupants; Public; NGOs; Investors; Infrastructure providers; utility companies; Policy Makers; Legislators; Banks *etc.*
5: Operation	Owners; Project Managers; Neighbours; Occupants	Designers; Investors; Solution Providers; R&D Institutions; Public; NGOs; Infrastructure providers; Utility companies; Banks *etc.*; Retailers and Distributors; Logistics
6: End-of-life	Owner; Planning Authorities; Waste Authorities; Local Government	Environmental Protection Agencies; Service Providers; Contractors; Public; Retailers and Distributors; NGOs; Infrastructure providers; Utility companies.

The key types of stakeholders for appropriate data generation were identified through brainstorming sessions involving the UMBRELLA project partners. In each of the study countries, a landscape survey provided an initial familiarity with actors filling the target stakeholder types and a scoping exercise provided a series of long-lists of both public and

[109] Occupants are typically perceived as those that live or work in buildings – other end-users, depending of the nature of building include: customers, clients, students, patients, inmates, *etc.*

private organisations, establishing activities and projects of relevance to the investigations. These long-lists were reviewed and further refined to develop short-lists of only the most relevant stakeholders. A database of contact points based on these short-lists was developed, including the details of potential key informants. Subsequently, candidate respondents were contacted by email or by written letter, with subsequent telephone call and/or email correspondence to arrange interviews. Furthermore, during the interview process, respondents were asked to recommend other stakeholders that would be of interest. In this way, snowball or chain-referral sampling was useful to identify potential respondents suitable for the focus of the study who might otherwise have been overlooked (Biernacki & Waldorf, 1981).

5.3.2 Interview process

As detailed on page 53, the in-depth semi-structured interview was chosen as the primary instrument for gathering information in this research. This method was selected as it was seen as offering the most effective means for capturing opinions and experiences, and for interpreting behaviours so as to better understand the interactions of actors within the value chains associated with building energy renovation projects. Semi-structured interviews set up a scenario in which an informant is provided with the time and scope to talk about their opinions on a particular subject.

While the interview guides or schedules that were developed were comprised of a list of potential questions of interest for the project, these were intended as a guide only (examples are included as Appendix 2 on page 307). Respondents were allowed to speak as much as they wished on any particular area. The questions were presented neutrally so that a desired answer was not implied. Stakeholders were interviewed face-to-face using semi-structured method, in an open-ended manner, in keeping with a 'grounded' type approach (Glaser & Strauss, 1967).

The schedules discussed above were intended to serve as guides for the conversation and were in no way meant to limit the conversation. Approximately one hour was allowed for each interview, although the actual length of interview varied with the informants. Wherever possible, and with the permission of the informant, interviews were recorded. The informants were talked through the purpose of the interview, the anonymity of responses was explained, and consent was obtained. It was made clear that personal opinions were being sought and not 'good' answers. The interviewer was free to elaborate on the 'question' text to guide informants and as appropriate follow-up on areas of particular note. Of over 100 interviews conducted, 58 interviews from 8 countries[110] were included in the analysis for this thesis[111].

Table 17 below presents a summary list of the stakeholders interviewed, categorised according to their role (note some are included in more than one category). While a summary of the national origin of the interviewees in included as detailed in Figure 37 below. Further details on the interviewees are included as Appendix 3 on page 321.

***Table 17**: Categories of stakeholders interviewed*

Role	Stakeholder Function / Examples	Key informant pseudonyms[112]
Finance	Banks and lending institutions; investors; donors & grant providers; insurers; quantity surveyors; accountants	Jean (FR), Alberto (IT)
Policy	International, national governments and local authorities; statutory control bodies	Rupert (DE), Jo (DK), Jans (DK), François (FR), Aodh (IE), Evita (IT), Viktor (SE), Hamish (UK), Philip (UK) Fred (UK), Alice (UK)
Waste Management	Waste Collection, sorting and haulage; recovery (salvage) & recycling; Incinerator / landfill operators	Séan (IE)
Project Management	Internal or external project manager (one stage or multiple stages)	Paul (DK), Michael (DK), Thomas (DK), Adam (DK), François (FR), Séan (IE), Peadar (IE), Róisín (IE), Giulia (IT), Umberto (IT), Evita (IT), Viktor (SE), John (UK), Hamish (UK), Fred (UK, Clive (UK)
Construction	Main contractor; sub-contractors & specialist contractors	Morgane (DE), Rogier (ES), Brian (SE), John (UK), Philip (UK)
Ownership	Internal project champion; business partners; management / board of directors; trustees; shareholders; housing associations; co-operatives	Jans (DK), Adam (DK), Miguel (ES), Pierre (FR), Marcel (FR), James (IE), Róisín (IE), Brian (SE), Ian (UK), Anne

[110] The 34 interviews in Ireland, Denmark, Germany and the UK were conducted by the author or by UCC team members working directly under the author; the 24 interviews from other countries were carried out by local partners under instruction from, and with the support of, the author.
[111] The interviews conducted by partners to be added to the UCC interviews, were selected on the basis of their relevance for the topic at hand.
[112] Where pseudonyms appear more than once the respondent has involved in more than one role

		(UK)
End Use	Occupants; occupiers; tenants; facility managers; staff, customers, clients, *etc.*	Eoin (IE), Ruairi (IE), Olive (UK)
Design	Architects; engineers; building assessors / auditors; ESCOs; owner representatives; specialist consultants	Anders (DK), Carl (DK), Mateo (ES), Olivier (FR), Bastion (FR), Áine (IE), Seamus (IE), Clodagh (IE), Séan (IE), James (IE), Valter (SE)
Industry	Raw material suppliers; manufacturers; haulage; wholesalers / retailers; education & training	Morganer (DE), Jörg (DE), Michael (DK), Eva (ES), Léa (FR), Peadar (IE)
External	The environment; property market / real estate media & advertising; other trend setters; utility providers; research & development	Kristoin (DE), Hens (DE), Paul (DK), Bjørn (DK), Marc (FR), Clara (IE), Roberto (IT), Valeria (IT), Maria (IT), Elsa (SE), Sven (SE)

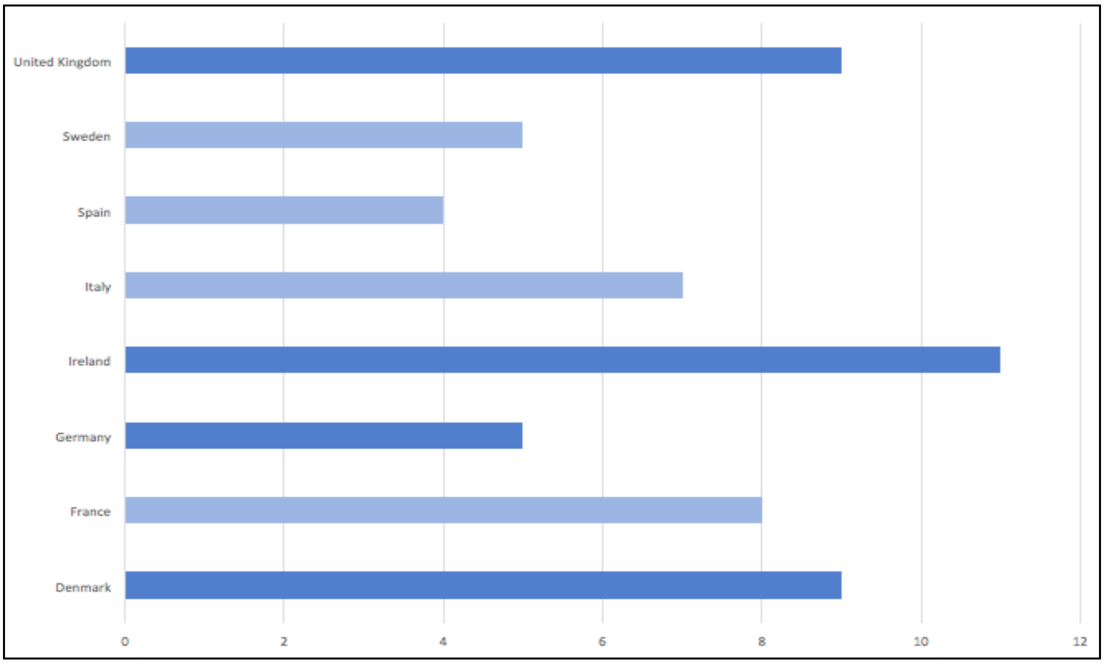


Figure 37: National breakdown of interviewees

Interviews were carried out during 2013, they were conducted face-to-face, in a private environment, a familiar and comfortable environment, in most case this was the place of work of the interviewees, in others a location of their choosing. Those interviews shaded darker blue in the above figure were conducted by the author directly or by researchers working directly for him in UCC. Those shaded lighter blue were conducted by researchers in partner organisations, instructed by and working with the support of the author. The interviews were recorded, transcribed, and for those interviews carried out by local partners, translated into English. In addition, where applicable, notes were taken to capture non-verbal communication or other relevant observations (Schutt, 2012). These transcripts were then ready for analysis.

5.4 Analysis of transcripts

5.4.1 Method

Transcribed interviews were qualitatively analysed through a thematic coding method. In this context, coding is described as the "*process of focusing a mass amount of free-form data with the goal of empirically illuminating answers to research questions*" (Hahn, 2008, p. 5). A code in qualitative inquiry is "*most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data*" (Saldaña, 2013, p. 3). Coding techniques are typically applied to help organise and analyse the considerable amounts of data (in the interview transcripts) that are frequently collected during qualitative research (Holton, 2010).

In this study, developed codes were used to segregate, classify, and group link data iteratively as patterns or themes were identified, and meaning and explanation emerged from analysis, using a form of template analysis[113]. This form of qualitative data analysis is favoured by those who find other methods, such as grounded theory, too restrictive, as it allows a degree of tailoring to meet the particular requirements of a study. Template analysis can also handle larger dataset than IPA[114], for example with the latter typically having less than 10 samples, while 20-30 would be common for the former (King, 2004, p. 257). Of course, there are well in excess of 30 interviews in this study, however the flexibility of template analysis allows it to handle larger databases, although this can be to the detriment of developing a particular understanding of an individual case (Brooks, McCluskey, Turley, & King, 2015). As the focus of this study is as much across case as within a case analysis, that is not a significant issue.

There are six steps in the procedure for carrying out template analysis, *viz.*

[113] As discussed on page 44, Template analysis comprises a group of techniques for organising and analysing data, rather than a specific method (King, 2004, p. 256).
[114] Interpretative phenomenological analysis

- Familiarise oneself with the accounts to be analysed. This may involve reading all accounts where the number is relatively small or a selection if the number is larger (Brooks *et al.,* 2015);

- Carry out preliminary coding of the data. This is similar to other qualitative analysis techniques; however, template analysis permits a priori coding (*i.e.,* from deduction rather than from observation). The interview schedule can provide a starting point for such codes (King, 2004, p. 259);

- Organise emergent themes into meaningful clusters, and explore how they relate to each other, both within and between these groupings. This can include both hierarchical relationships with broader ones, as well as lateral relationships across clusters (Brooks *et al.,* 2015);

- Define an initial coding template. This is typically done using a small sub-set of the sample. King (2004, p. 259) reports using just two accounts for a this task, and notes the advantage of involving others at this stage – if for no other reason than to "*force the researcher to justify the inclusion of each code"*;

- Apply the initial template to further data and modify as the initial codes appear inadequate. Modifications may include insertion, deletion, changing scope, changing higher order classification (King, 2004, *pp.* 261–262);

- Finalise the template and apply it to the full data set. Brooks *et al.* (2015) observe "*In some respects it should be said that there is never a 'final' version of the template, in that continued engagement with the data can always suggest further refinements to coding*", while King (2004, p. 263) comments that "*one of the most difficult decisions*" is to know when to stop developing the analytical template.

5.4.2 Implementation

Organisation

Due to the large number of accounts, a similar division of work was implemented. The author and the UCC team analysed the transcripts arising from the interviews in Ireland, Denmark, Germany and the UK, while the other transcripts was analysed by the local partners under the direction of the author. Prior to starting the analysis, a one-day coding workshop, led by UCC, was held to coordinate activities and to instruct the local partners in coding and in the use of the NVivo software[115]. To ensure consistency of approach, there was constant communication during the analysis, including a question and answer mailing forum which was maintained throughout the coding and analysis process, to highlight challenges encountered, potential pitfalls and solutions to common problems.

Coding

In keeping with the template analysis procedure detailed previously, the first task was to become familiar with the accounts to be analysed. To this end a selection of transcripts representing different stakeholders and different countries was read. This (re)familiarisation with the material was a necessary precursor to planning the coding, and a useful starting point for the preliminary coding. As expected, the principal headings in the interview schedules provided the initial a priori codes *viz.* building/project, energy use, energy renovation, marketplace, stakeholders and sustainable development.

Séror (2005, p. 323) observes that "*Good qualitative research involves meticulous data sorting and organization and carefully using ideas generated by the data*". NVivo software from QSR was used in this research (see Bazley, 2007). The software is designed to help organise, analyse, and find insights in qualitative data such as interview transcripts. Within NVivo, coding takes place through use of 'nodes', which are effectively containers of information, each containing extracted references and excerpts from the source material,

[115] NVivo is qualitative data analysis software, which takes the place of the traditional methods of highlighting, underlining, and (literally) cutting, pasting, copying, and categorising volumes of printed text.

and labelled to capture the meaning of all constituent reference material extracts. Nodes can also be used to record metadata associated with the interviews *e.g.*, interviewees, organisations, and projects. In this way nodes can be used in two ways, *i.e.*, for both analytical and descriptive functions. However, it should be noted that NVivo is still just a tool for facilitating the mechanical steps associated with the analysis[116] – however, the analysis of the material is still very much in the hands of the researcher. The initial codes were subsequently refined and further developed during the coding of the transcripts. An initial coding template was prepared and shared with all partners to ensure a common starting point. Changes to the codes were periodically communicated and partners exchanged a number of transcripts during the analysis process to ensure the coding was aligned. As the coding process advanced, relationships between the codes became apparent, the template was thus structured in a hierarchical manner denoting such relationships. When coding was completed, a summary of each coding node was written up, highlighting key points from the interviews, supported with quotes. The material was then organised under headings reflecting the objectives of the research.

The actual process of using NVivo can be summarised as thus: (i) import of transcripts into NVivo as 'sources', (ii) initial review of source, including using tools such as word search, word cloud, *etc.*, (iii) coding of the transcript, noting emerging concepts, (iv) perform 'queries' to ascertain relationships between codes, (v) review and reflect on material, (vi) visualise codes in written and graphic form, and (vii) repeat process in a reflexive manner, refining, rearranging and consolidating codes, developing insights, and exploring the relationships between codes. Figure 38 below presents the final coding template, wherein the various codes developed in the analysis were consolidated and standardised.

[116] Séror (2005) gives the example of regrouping an informant's data in one folder or category whenever new data is added.

1) **Knowledge**
    a. Education and training needs
        i. Reluctance to train
        ii. Integration of energy topics
        iii. Misinformation
    b. Public awareness
        i. Engagement
        ii. Communication
        iii. Awareness raising
        iv. Demonstration projects
    c. Research and Innovation
        i. Research
        ii. Transferability
        iii. Niche space
        iv. Innovation networks
    d. Networks
        i. Formal partner
        ii. Informal links
        iii. Stakeholder links
        iv. Multi-sector links
        v. International links

2) **Marketplace**
    a. Opportunities
    b. Customers
    c. Innovative products
    d. Competition
    e. Market expectations
    f. Financial crisis

3) **Business planning**
    a. Organisation
        i. Structure
        ii. Decision making
        iii. Capacity
        iv. Internal dynamics
    b. Project delivery model
        i. Type
        ii. Partners
        iii. Key suppliers
    c. Business model
        i. Financing
        ii. Costs
        iii. Payback, ROI, *etc.*
        iv. Economic viability
    d. Risks

4) **Project**
    a. Motivation and drivers
        i. Regulatory
        ii. Financial
        iii. Reputational
        iv. Societal
        v. Other
    b. Barriers
        i. Policy
        ii. Financial
        iii. Knowledge deficit
        iv. Building control
        v. Other
    c. Objectives
        i. Success metrics
    d. Technical
        i. Solutions
        ii. Energy metrics
        iii. Other metrics
        iv. Assessment
        v. Energy sources
    e. Approval, permits, *etc.*
    f. End-user behaviour
    g. Stakeholders
        i. Types
        ii. Roles
        iii. Involvement

5) **Society and Policy**
    a. Legislation and policy
        i. Building regulations
        ii. Political decisions
        iii. Policy instruments
        iv. Industry lobbying
        v. NGO lobbying
    b. Social issues (and opportunities)
    c. Environmental consciousness
        i. Climate change
        ii. Life cycle perspective
        iii. Global approach
        iv. Sustainability
    d. Cultural differences

Figure 38: Consolidated final coding template

5.5 Review of chapter

This chapter outlined the work undertaken to understand energy renovation project delivery. It presented the developed *Hubs of Activity* model, which can be used as a frame for understanding construction activities. The details of the stakeholder interview process were outlined and discussed. Finally, the method for the analysis of the transcripts arising from the interviews was presented and practical realisation of the transcript analysis method outlined.

Chapter 6 below, outlines some insights on the *Hubs of Activity* model derived from the stakeholder engagement while Chapter 7 presents principal findings from the interview analysis.

6 Insights on the hubs of activity

"Discovery is seeing what everybody else has seen, and thinking what nobody else has thought" – Albert Szent-Gyorgyi

As a means of better understanding key activities in renovation projects, a mapping exercise was carried out for each *Hub of Activity* presented in Section 5.2. Building upon the information gathered from interviews, this process aimed to detail actors, influences, outcomes associated with, and identify key relationships within each stage. This was used then used to develop illustrative power-interest matrices of relevant stakeholders. In short, this chapter uses the *Hub of Activity* model as a framing mechanism for an initial exploration of the collected information presenting insights on each of the six stages.

6.1 Upstream

Figure 39 below shows illustrative actors, influences and outcomes associated with activities upstream of construction, which provide the materials, energy, equipment, *etc.* required for a renovation project to be realised. Actors are number and listed on the shaded area on the left-hand side. The key actor and the outcomes of the stage are presented in the shaded area on the right-hand side. While anything that influences the outcome is included in the central portion of the schematic and labelled by letter. Where an actor or influences affect another influence the numbers and/or letter are displayed beside relevant box. For example, in the figure below the technology context is associated with manufacturers, R&D institutes and standard bodies while being influenced by the regulatory context and research context. The lead actors (*i.e.*, those with most influence on outcomes) at this initial stage are the manufacturers of materials and products, with a number of other important actors including those associated with upstream inputs, policy and regulation, finance, research and standards, distribution and retail, neighbours and the general public. These actors both effect, and are affected by societal, regulatory, technological, fiscal, economic and market contexts, all of which feed into the decisions made by manufacturers and thereby influence which solutions are available on the market, what their price will be, and the nature and quantum of the associated environmental burdens – the 'outcomes'.

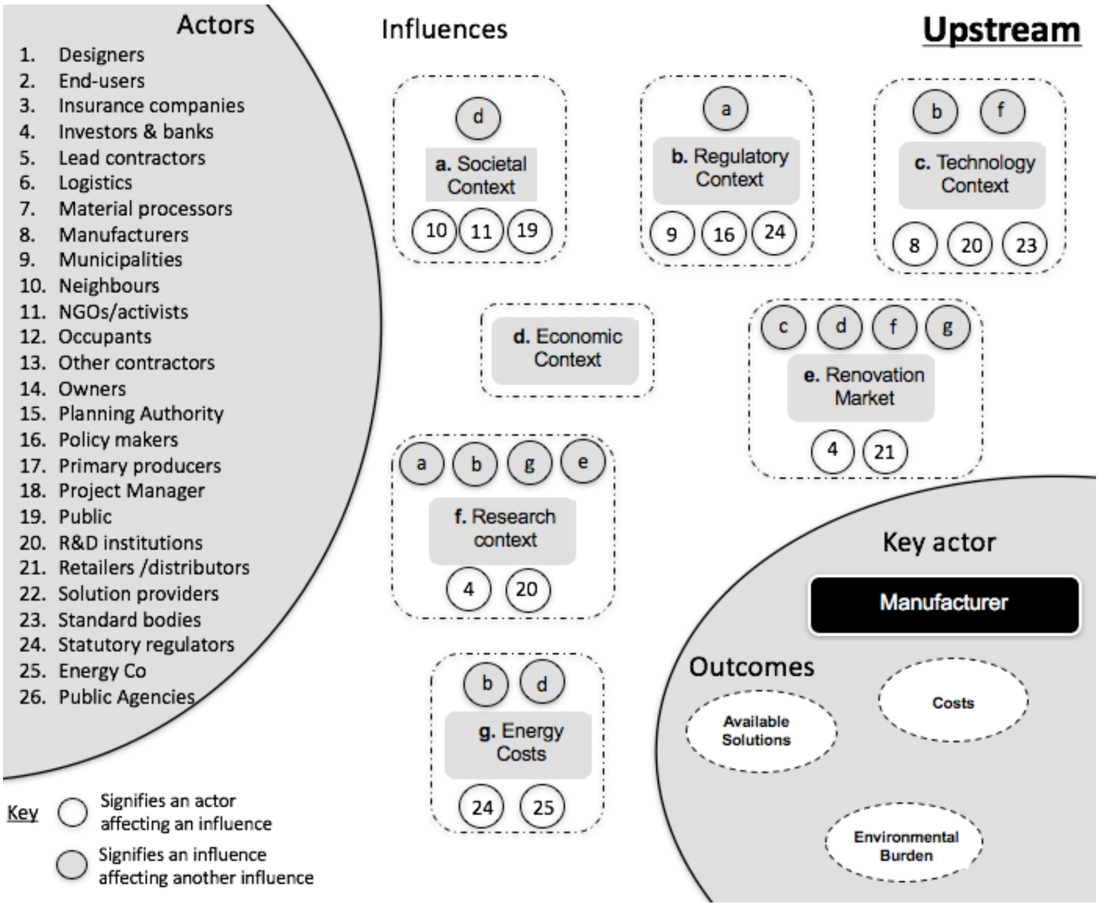


Figure 39: Actors, influences and outcomes associated with upstream activities

The solutions and products applied in construction projects (and indeed energy renovation) are greatly influenced by local markets, which are in turn influenced by the local availability of resources and the market power of local manufacturers and suppliers. For instance, the timber industry is a powerful voice in Nordic countries[117], while in others which traditionally had less woodland, such as Ireland[118], the concrete sector is perhaps just as powerful[119] [120] – the influence of these sectors in specific countries has greatly influenced the adoption of

[117] The Nordic timber industry comprises a large indigenous base built on availability of wood.
[118] Originally an island covered in woodland, Ireland was substantially deforested in the 16th & 17th centuries, (Neeson, 1997, *pp.* 139–143), to the extent that by the start of the 20th century just 1.4% of the country was under forest (Ní Dhubháin, Walshe, Bulfin, Keane, & Mills, 2001). Although, since then and particularly the last three decades, a substantial afforestation programme increased that cover, such that it was 11% by 2015 (Bonsu, Ní Dhubháin, & O'Connor, 2015), the forestry/timber sector is still very much a young industry, with relatively little influence.
[119] See *e.g.,* Reid's (2006) news story on the alleged influence of large Irish cement manufacturers.
[120] Especially as the sector coalesced around a couple of large players, including CRH plc, which is large even by international standards (Barjot, 2013).

specific construction materials and methods[121]. Relevant stakeholders from this stage are presented in an illustrative power-interest matrix in figure 41 below – following Johnson, Scholes, & Whittington's (2008, p. 156) approach to stakeholder mapping adapted from Mendelow (1981).

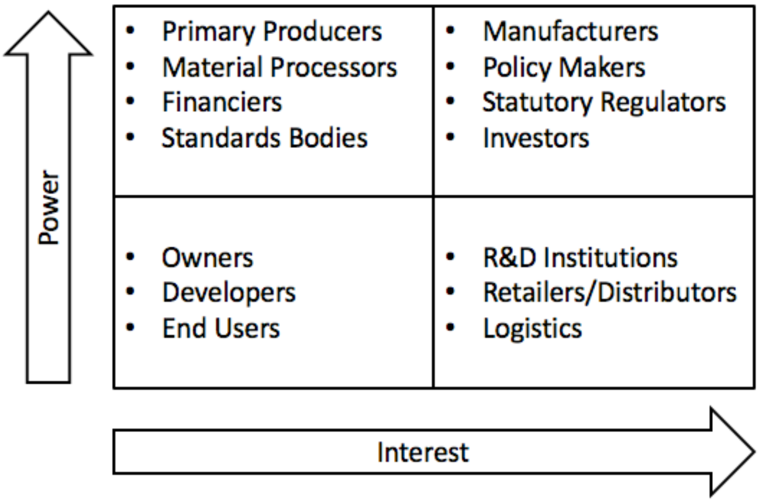


Figure 40: Power-interest matrix for upstream stakeholders (derived from Dunphy *et al.*, 2013a)

The power and interest of the stakeholders will differ somewhat from project to project and will of course change over the course of the project (compare the matrix above with those from the other hubs of activities on *pp.* 176 to 201).

Notwithstanding the evident implications of these upstream activities for later stages and indeed renovation activity as a whole, it was notable how little reference was made to these activities by the respondents (this lack of interest is reflected in the position of developers in the above matrix). Even when talking about specifically addressing life cycle aspects there was little real consideration of those activities which occur before the construction phase. For example, Rupert[122], a German building control official, in attempting to describe the concept of life cycle said that it would mean that

[121] As demonstrated by the slogan of the Irish Concrete Federation '*Concrete built is better built*'.
[122] In discussing the data arising from engagements, I am using pseudonyms for the participants, rather than participant-identifiers. This is a deliberate decision reflecting the nature of the research, and emphasises the centrality of people and their opinions to the study – respecting their subjectivity as persons, rather than as mere sources of data. All persons quoted are anonymised using names arbitrarily selected from popular names for each country.

> *"... under the aspect of sustainability that the lifecycle(s) are more durable or more (sic) or at least more-easy to recycle materials should be used".*

Here, Rupert is considering the lifecycle only from time of purchase, emphasising the durability and longevity of the product. He does not acknowledge upstream implications and while he acknowledges the desirability of recyclability, it is framed almost as an afterthought. This aligns with the view of Jörg, a manufacturer of insulated wall systems in Germany, for whom life cycle equated with the longevity of their products. He sees this as a key part of their offering, and comments that the lifespan of the system is

> *"critical because, especially if you get like in the UK where you get a financing model being in place where you have to prove that a lifespan of at least 25 years, all of our products are undertaking some testing procedures - these testing procedures are regulated in either standards or we rely to the DIBt [Deutsches Institut fur Bautechnik] where the approval system are being regulated and within that testing procedure we simulate a lifespan of 35 years".*

It is not that Rupert or Jörg necessarily do not understand the life cycle concept, but rather in their minds the concept is conflated with the longevity of products. Even when prompted on life cycle sustainability, both of them found it difficult to move away from a product focus and spoke of the moves to increase the recyclability of their products. Even those respondents that did allude to upstream impacts did so in what may be termed a half-hearted manner. For instance, Morgane from a training centre in Germany observed:

> *"concerning the lifecycle, it is of course better to retro-fit an existing building than to build a new one than to break it down and to build a new one, that's so to say, it's implied into this".*

In the above comment, Morgane is explicitly recognising the energy and resources embodied in the existing buildings and in contrast to the previous respondents, she is at least partially considering upstream impacts. However, in spite of this implicit acknowledgement of the importance of lifecycle perspective, Morgane concedes that it is not reflected to a significant extent in the training and educational offerings of the training centre, just commenting that "*we try to bring into mind. It's an aspect – ja*". Here it can be seen that while upstream impacts are recognised, they are regarded as almost peripheral in their construction education programmes.

However, there was some mention of specific upstream impacts – specifically energy and 'carbon' (*i.e.*, upstream energy consumption and GHG emissions) were noted as important factors in the sustainability of buildings. Such consideration was considered to be of growing importance for Marcel, a French developer who said:

> *"Before for (selecting) materials – you took concrete because it carries the load and you do a calculation and it's done. Now you take concrete and you question the embodied energy, how do I dismantle it, and for sure things are getting more complicated, compared to 10 years ago. For me this is the normal framework".*

While Áine, an Irish architect commented:

> *"you have got to look at your priorities, and my priority would be to start off with the energy use of the building in its lifetime, and then next look at its embodied energy, and then look at the wider scope of the building, its*

place, which not every client has the choice, the impact of the building on its environment as a whole…"

For both Marcel and Áine considering the upstream energy consumption, associated with material choices, is now (for them) normal practice, albeit not necessarily a priority. It is apparent from some of the responses that many individuals are moving quicker than their organisations, and an impression was given by some that they personally would assign greater priority to such considerations. Clodagh an architect from Ireland, e.g., stated:

"I would look into that (Cradle to Cradle) and that would drive it for me personally, but that wouldn't necessarily be the policy of the office, the policy of the office would be: get as good a product, for as cheap as possible, and certification I suppose – but for me, reducing the embodied energy would come into it".

It is evident from the certification comment, that Clodagh is not referring to sustainable building certification (such as BREEAM or LEED, as they would include measurement of embodied energy), but rather to building control certificates. It is clear that while consideration of upstream impacts is to some extent making its way onto the agenda, it is doing so relatively slowly[123]. Although environmental product declarations (EPDs as mentioned on page 114) are increasingly available for construction products and materials (prepared using life cycle assessment and life cycle energy analysis tools) – they were only tangentially mentioned, such as when Valter a designer from Sweden, said:

"So, in the best world it's just looking at it from a very long-term perspective, not only reducing the cost of the material but also be

[123] In this regards an observation from Léa (a French smart meter manufacturer) that "*the embodied energy concept is not for 1/10 or 1% but for 1/1000 of the population*" is demonstrative of the continued niche nature of interest in upstream impacts.

beneficial from an environmental perspective. So, I wouldn't say it's only the cost but also environmental aspect. Being able to get good certificate for example, but there is a lot of research going on in that fields, because we need better tools to understand this".

Through this comment it is clear that Valter considers the life cycle assessment of construction products (and by extension of construction projects) to be at an early stage. In this regard, there is a noticeable lack of patience amongst some policy makers on the pace of adoption of such tools and progress in minimising upstream impacts. For instance, Aodh from an Irish local authority advocated that:

"there should be something like a stick and carrot, something that cause architects to reduce the amount of embodied energy".

Although Aodh appears to be explicitly pointing to building designers for the lack of progress in reducing embodied energy, it is clear that in saying architects he is referring to all those involved in design – not least to the owners and developers who ultimately decide on the nature of projects. In this respect, Marcel, a French developer posited that:

"we owners are perhaps not enough demanding" while also noting that "in another way I'm hypocritical, I commission an architect and then after I ask a company to build the building, and so me I'm not very engaged in the process. I'm just saying I want a nice-looking building of 10 000 m² for €20 million, and after do as you like".

Marcel is conceding here that developers such as he, could, and arguably should, be more demanding of the building designers that they employ and by extension of the building projects that they instigate. Delivering value (including potentially 'green' metrics) in renovation projects requires the development of common purpose and shared objectives and the clear communication and explicit articulation of goals.

6.2 Initiation

While often overlooked, in considering that various tasks involved in construction activities, 'Initiation' is fundamentally the most important stage of a construction project – it is as this juncture when a judgement is made on the viability of a proposed project and a decision is made for a project to commence or not. It is at this decision-making stage that the perception of risk is perhaps at its greatest – the potential to lose money, the risks of not achieving sufficient savings to pay back the costs, the risk of selecting inappropriate solutions, *etc.* Figure 41 shows the Hub of Activities occurring at the project initiation stage, including a description of actors involved, the range of influences on these actors and potential outcomes.

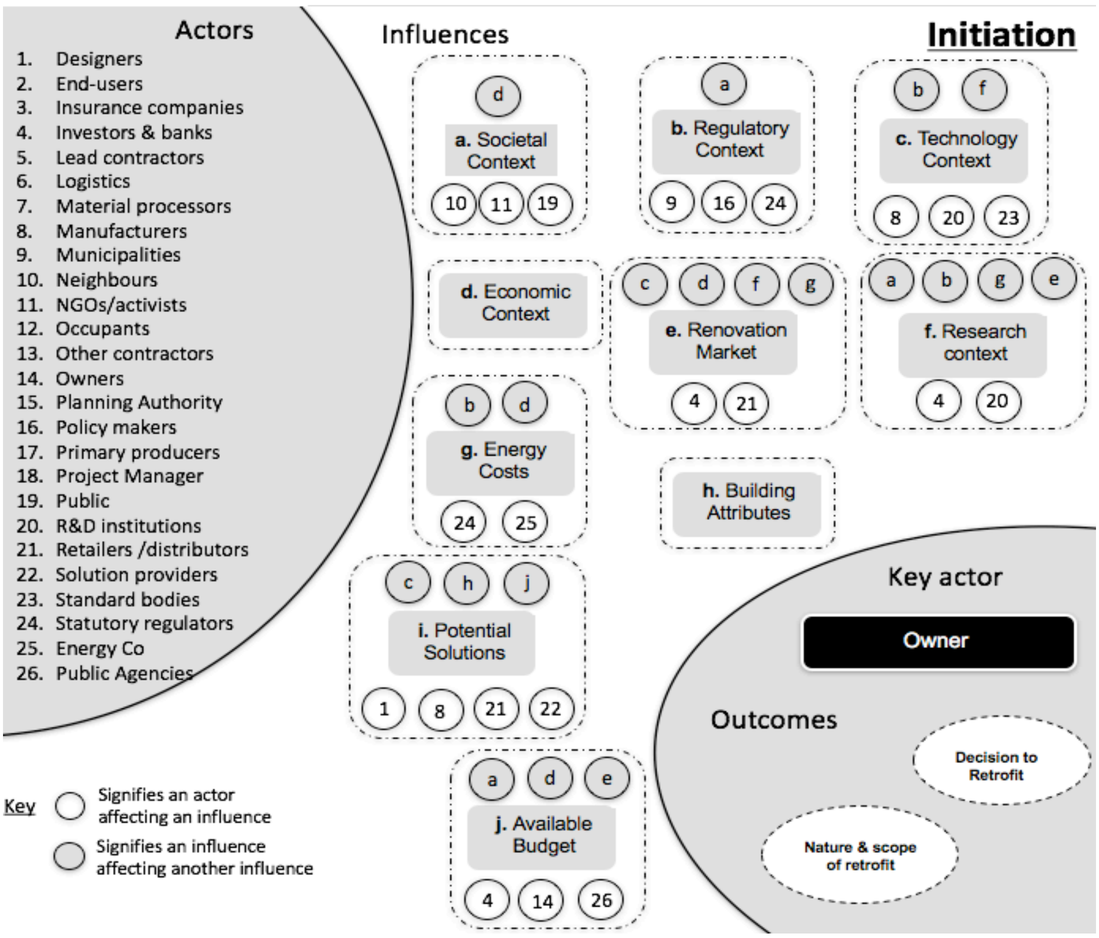


Figure 41: Actors, influences and outcomes associated with initiation activities

Not unsurprising in the generic project depicted above, building owners are identified as the lead actors in initiating projects, and while the influence of third parties may vary depending on the particulars of projects, the owners of a building will remain the key player in any proposed renovation. The owner as the project initiator (in the vast majority of cases) has a determining role in defining value for the project as a whole. Final project outcomes, defined by success criteria forwarded by the project initiator, will be applied to assess the performance of individual contributors. While monetary exchanges will be used to confirm that the required performance standard has been met, such standards are undoubtedly linked to a variety of success criteria, or value definitions. In practice, there is a hierarchy of values within a project, and that the stakeholder with most financial and organisational power (typically the owner / developer), will get to place their definition of value(s) in a paramount position. Contractors have to respect the value proposition of stakeholders with higher power-interest stakes in order to receive their payment in a timely fashion. Relevant stakeholders from the initiation stage, are presented in a power-interest matrix as Figure 43 below.

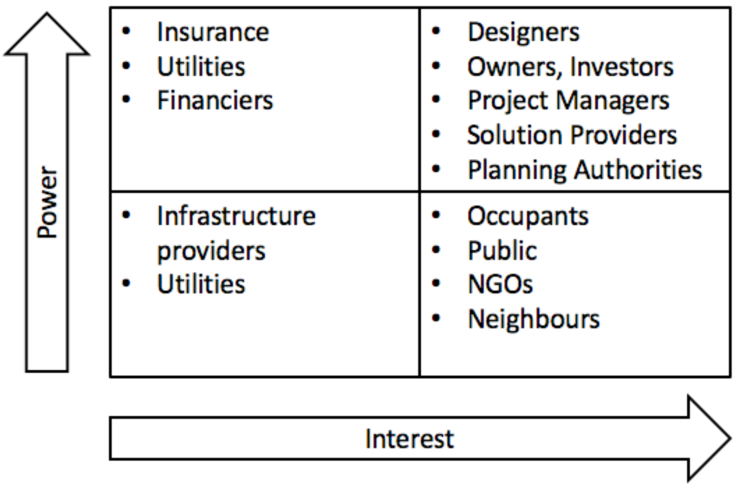


Figure 42: Power-interest matrix for initiation stakeholders (derived from Dunphy *et al.*, 2013a)

The concept of owner may not always be simple, the ‘ownership’ of a development can be quite complicated, whether this be from a legal perspective or in practical terms – this complexity can make such decision-making more difficult. The most obvious ownership legal complication is where there are multiple owners *i.e.*, co-ownership[124] of properties – in the case of multi-unit developments (*e.g.*, apartment blocks) there is the added issue of so-called common areas[125], which will complicate matters even more. Hastings, Wong, and Walters (2006, p. 297) observe problems in collective action for such co-ownerships commenting "*since, all co-owners are inter-dependent and have the right to participate in the decision-making process, the decision becomes a collective rather than an individual choice*". Altmann (2014, p. 437) agrees saying that "*retrofitting existing buildings with shared governance structures is sometimes viewed as problematic*". This emphasises the need to understand different people's perceptions of value such that a shared vision will be more achievable. The interview with Jean from a French Public Association emphases this point, when he says:

> *"That's why I was telling you, the project cycle is quite long and we need to take into consideration governance aspect. There is not only one owner but sometimes 100 lots with often 100 owners. So, you have to follow the co-ownership decision-making rules. Those rules are framed by the general assembly of the co-owners where they took the decision of pursuing the works or not".*

Jean is pointing out the long lead in time for such decision making, where meetings are held infrequently. Olivier, a French architect makes a similar point when he says:

> *"Well we are currently, it has been already one and a half years that we are working on it, it is very slow. Because decisions are taken in the*

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[124] This can take a variety of shapes depending on number of factors, including the legal code in a particular jurisdiction but all such co-ownership will result in some form of shared governance.

[125] In Ireland, for example the ownership of the apartments is vested in the individual owners while common areas (such as external walls, roofs internal load bearing walls, hallways, landings, *etc.*) are owned by an owners' management company – Multi-Unit Developments Act, 2011 (No. 2 of 2011) Oireachtas Éireann

> *general assembly that is once a year, so if it's badly presented and the general assembly says 'No' – we have to wait until next year".*

The frustration from the respondents is evident in their responses where they present the structure of the ownership as a problem. For example, Olivier's feelings can be summarised by his comment that "the great difficulty in co-ownership buildings, (is) because you have non-professionals". Here Olivier is laying the blame for the difficulties firmly on the owners and implicitly suggests that things would be less problematic if the 'non-professional' owners were not so central to the decision making. This is in contrast with the next example, an intentional community based in the UK, where the involvement of co-owners in the decision making is not only seen as valid but acknowledged as the only way to achieve key collective action required in co-ownership scenarios.

Anne from the UK describes the intentional community in which she is a leading member, as comprising:

> *"… maybe three or four hundred individual households, there are over 35 businesses and small charities, and limited liability partnerships and co-ops and all that".*

Decisions are taken in this community is largely by:

> *"… consensus or unanimity or, and if we can't get agreement, then we reckon that we aren't there yet, and something else needs to be thought about".*

Here Anne is describing a fundamental feature of her community – the decision-making process which she defines as "*dynamic self-governance, holocracy or sociocracy*"[126] – in that while it is consensual in nature, the aim is not to select an option with which everybody agrees but rather finding an option, to which there are no strong reasoned objections[127]. The network of entities and individuals which make up the community and the nature of decision-making means that in Anne's words:

> *"… sometimes that takes forever and something doesn't happen because we can't agree, but we also have learned that if … we push through that and make something happen, because it has to happen".*

In Anne's community's decision-making process, the focus appears to be very much in bringing people along with the proposed action, whereas in the interviews on co-ownership in multi-unit developments – it appeared that the co-owners are perhaps tolerated more than welcomed in the decision-making process. Thus, it can be seen that the nature of the owner and of ownership has implications for the initiation of a renovation project. The lessons from implementing and achieving consensual decision-making in intentional communities such as Anne's may have useful wider application in other forms of co-ownership. Moreover, the communication with key stakeholders (such as co-owners) needs to be tailored to take account of their views and perspectives. Áine an Irish architect, makes the point:

> *"So, it's never just a financial decision, it usually comes from an ethical, environmentally responsible point of view, where you go - ok I know is going to cost me, but I want to do my bit for the environment, I want to make that outlay".*

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[126] Rios (2011) provides an interesting account of the application of sociocracy in an intentional community, which is very much in keeping with the practice in Anne's community

[127] Or as Anne describes it "the essence of that decision making process is if you haven't got a strong reason to block it, let it happen, and then pull it back for a review, as opposed to waiting until its completely prefect before you can say yes".

In this statement Áine is capturing the view of clients for whom, the value of a potential renovation is more than such its financial return or even increased comfort – she is explicitly recognising that for many, wider societal and environmental considerations come into play and perhaps implicitly acknowledging the importance of the greenhouse gas as a metric for building energy renovation projects. Valter, a Swedish architect presents a similar picture saying:

> *"in terms of energy efficiency, I mean even if we were working so long with sustainability, we have kind of disseminate that knowledge throughout all company, like I said we have an environmental specialist that is taking part in all the projects. It gives an added value that is never forgotten, in any project".*

It is evident from both of these responses that the personal values of stakeholders can be a motivation in building renovations. In deciding on renovation project initiation, owners of buildings will be conscious of the financial assets at stake, but may have limited awareness of the technical options available, be unsure of other stakeholders such as contractors, municipalities, and may have limited access to technical and financial guidance. Bastion, the owner of a French engineering firm commented that:

> *"There are political barriers in terms of decision making, so if there is no clear sign, people continue to 'spin around' saying It's expensive".*

While he is describing the issue as a political issue, it could also be argued that the core of the problem he describes is lack of knowledge – the reference to political barrier may reflect more on French expectations of their government. Many people are of course risk adverse and in the absence of clear information of the advantages of a project will be reluctant to proceed. Anders, A retrofit designer in a large Danish consultancy gives the example of a housing cooperative

> *"… I think the board of this cooperative they were very old fashioned so they didn't want to do that but actually it could have been an alright business for them but of course we could have failed in doing this and so on there could be a lot of things we didn't know from the beginning, we would only know when we started and so on, so of course there is a risk".*

Notwithstanding new technology, retrofit projects frequently produce unexpected problems, particularly with older buildings where issues only manifest when building works begin, facades are stripped away and underlying problems present themselves. The contractual and legal arrangements for retrofit need to be designed to accommodate such unforeseen issues, including need for additional works and associated time-delays. These may be best addressed at the initiation of a project. The mitigation of risk has a high, if often unspoken value amongst stakeholders. One means of achieving risk mitigation is for a detailed analysis to be carried out and for this to inform the provision of comprehensive information to project stakeholders, to allow fully informed decision-making and the explicit acknowledgement of potential problems and likely risks.

One approach to deal with risk aversion is to couple energy renovations with routine scheduled work. Eoin, an Irish public sector project manager spoke of how his organisation used such an opportunity to incorporate addition energy efficiency works has:

> *"The boiler house … was due to be upgraded, because the gas boilers that were there were probably 20-25 years old, they were reaching the end of their useful life. We decided to take the opportunity. We knew we had to upgrade the boilers, it was a case of do we do it this year, do we*

do it next year, do we wait until they shut down on a cold winters day and we have to shut down the building. The decision was made to do it, maybe sooner rather than later. The decision was made to combine that with putting in more energy efficient boilers, upgrading the BMS, putting in TRVs and solar panels, doing the lighting upgrade, doing it all as one package, but the driver was purely because we knew the boilers were about to sit down".

The case described by Eoin is a typical example of opportunistic leveraging of planned works to 'piggy-back' energy efficiency works, where on their own, they may not seem so urgent and decision may be delayed if indeed ever made. In countries such as Germany, building owners (particular home owners) are reluctant to take on debt, due to cultural issues. Hens from a German construction research organisation in Germany comments:

"… I think the people don't like the low interest loans, the normal house owners because they don't want to take the credit they like to have more the direct cash, so I think this is more successful".

In countries of the European periphery, the economic crisis and pre-existing high levels of debt ensure that householders and business owners are reluctant to take on further debt, coupled with the fact that credit may not be available in these jurisdictions in the first instance. Ciara from an Irish utility sees a lot of risk arising from the recent recession, which hit Ireland harder than most, she says:

"So, there are a load of things that are all tied up with recession which are making it more difficult to push ahead the retrofit market I would say".

Here Ciara is acknowledging the inherent risks in dealing with businesses and home owners that are (still) relatively highly leveraged – she poses fundamental questions for a typical 5-year payback term renovation project "*will the customer be there in 5 years?*" and "*will the company be there in 5-years*". This (perceived) risk for both customers and suppliers is seen as restricting renovation activity.

The role of the public sector is critically important at present in terms of the initiation and viability of projects at present. The public sector has the potential to act as a catalyst for considerable added value generation across the energy efficiency retrofit marketplace. For instance, Carl a Danish architect highlights the significant role the government plays in Denmark in promoting energy efficiency in buildings, saying:

> *"There is a general push to advancement because the government is pushing it quite a lot and many organs are pushing it. All the leading partners in the building industry, state finance, buildings, they are very aware of it. For common people, its silently growing, in a more 'calm curve'. I guess you find more and more who would demand it of an architect, but it's getting there because they have to".*

The scenario presented by Carl implies a level of coordination between public policy, state agencies, financiers and industry which is leading to increase in both high performance new buildings and energy renovations of existing stock. However, government intervention is not also perceived as a good thing – John a UK contractor, for example, comments that:

> *"probably just that a lot of the way things are run is to just follow the gravy train, and it's not always the best-case scenario, because the government puts out these incentives and things and sometimes people are just doing it for the gravy train".*

While, there may be an element of 'sour grapes' in his observation, in saying this, John is highlighting the ability of government incentives to shape (or in a more pejorative perspective to skew) the marketplace– and in doing so directing resources to activities which may not be the most effective at increasing energy efficiency of building stock (or indeed of addressing other significant policy objectives *e.g.*, reducing greenhouse gas emissions, addressing fuel poverty, *etc.*). Moreover, the relatively short-term nature of government policy compared to the pay-back time of some investments means that any such skewing of the market place is subject to change, as related by Mateo from a Spanish engineering consultancy when he spoke about the supports for renewable energies:

> *"as a reminder legislation in Spain made renewables very attractive in a first stage, and some years later the government changed the conditions radically".*

Here the desire for consistency and dependability of policy is highlighted as an important factor in making a decision on initiating projects. Seamus an Irish architect comments that most of the finance that his clients utilise is private, saying:

> *"the grant is the bonus, often I never integrate the grant into the budget, to say you have this this this minus the grant. I never present the budget that way because with the grant you are not sure that you get them anyway so it's just a bonus".*

The implicit statement from Seamus is that governmental financial support cannot be relied upon and that projects need to make financial sense on their own. Kristin a German Research and Development Coordinator spoke of the complexity of accessing support:

> *"... in Germany, we have so many different types of funding for new building, retrofitting buildings, so we have so many different conditions for funding it's so complicated and they change every year or two years they change and if you want to apply for DGNB or LEED or whatever you have to take another step and another plan you have to made or another concept or another data you have to evaluate".*

Kristin is highlighting that there are often difficulties in obtaining available supports and implicitly querying if the support is worth the hassle of applying for it. The existence of this perception also suggests that there is scope to improve the effectiveness of public policy instruments in this area by making it more user-friendly for stakeholders. Moreover, renovation of existing building stock is a good example of where environmental policy integration (EPI) *i.e.,* "*the incorporation of environmental concerns in sectoral policies outside the traditional [environmental] policy domain*" (Runhaar, Driessen, & Uittenbroek, 2014, p. 234) can contribute significantly to achieving multiple goals (see Mullally & Dunphy, 2015 for a comprehensive overview of EPI).

However, finance can be an issue for many public-sector organisations also, Miguel a Spanish developer observed that:

> *"city councils are paralysed because of the enormous debt that they are not able to pay".*

He is highlighting a significant issue for those countries, such as Spain (and their sub-national governments), which still carry legacy debt from the 2008-2016 financial crash. The inability of the public sector in many countries to play a leading role in renovation activity substantially restrict renovation activity in public housing and other buildings and reduce the support that these public actors can give the private sector in this area – Miguel suggests that for the medium term at least:

> *"private companies will have to work and use their expertise alone, without the help of the public bodies … to wait for a better financial situation of Spain".*

Miguel is saying in effect that public support, whether financial or otherwise will not be readily available until the resolution of the financial crisis

Under the current economic environment, energy efficiency renovation projects are often not sufficiently attractive to private investors with capital to invest. Notwithstanding the previously discussed problems and challenges facing many public authorities, there is substantial scope for them to increase their role in promoting and facilitating renovation activities. They have a key role to play for a number of reasons including: financing capacity[128]; ability to support risk; direction-setting for the sector; public building stock on which to perform works; *e.g.*, through instigation of innovative business models (all of which were indicated in respondent Carl's description of the Danish situation on page 183). The public sector can initiate projects, and through involvement of private sector partners, can encourage and promote innovation and skills development, as well as project level lessons across the construction industry. Through leveraging public finances, municipalities and public authorities can shoulder a proportion of risk, which may serve to encourage private sector stakeholders to come on board with projects, while new and innovative business models can be trialled and demonstrated.

6.3 Design

Bertelsen (2002, p. 7) argues that: "*Only in the early design phases can construction make use of the top-down process best supporting creative work*" and observes that while other

[128] Notwithstanding the issues raised in some countries during the interviews concerning the post-crash austerity in many countries, governments and public authorities will generally be able to access lower cost funding than private companies

creative and project-based industries such as provision of information technology services and movie-making tend to maintain top-down process in operation almost until the final production stages, construction is forced to abandon this approach before one-tenth of the process is completed. Here Bertelsen is contrasting the (for all intents and purposes) absolute control of a movie director with the more distributed control exhibited in construction activities. This argues for close and well-structured cooperation between the customer and the construction team in the early phases (such as design) of any given renovation project. However, Bertelsen suggests this is not typically the case.

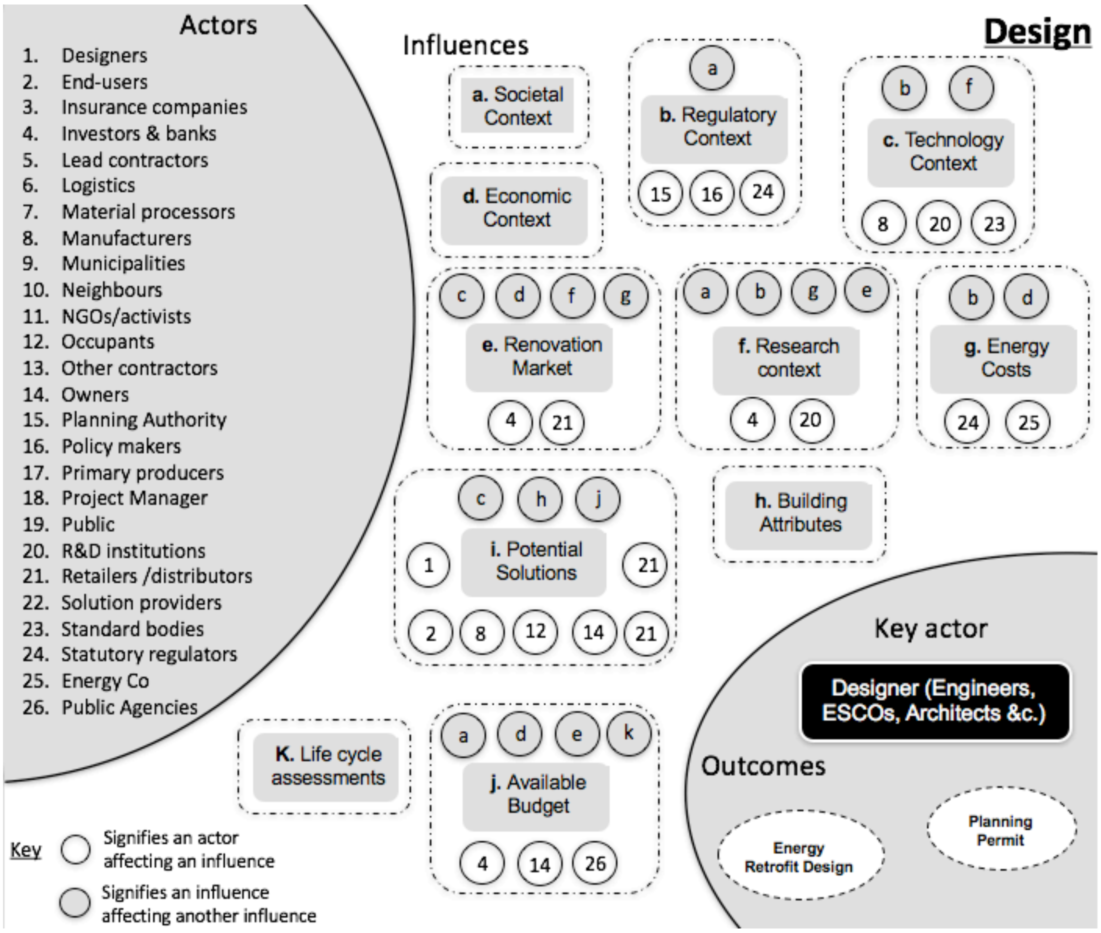

Figure 43: Actors, influences and outcomes associated with design activities

Figure 43 above shows illustrative actors, influences and outcomes associated with the design stage. The most influential actor with the design hub of activities is not surprisingly the designer, which depending on the project may take the form of an architect, an engineer or even a multidisciplinary team.

Although rarely explicitly stated as such early contractor involvement emerged as a theme of key importance from stakeholder interviews. Jo from a Danish municipality describes her organisation's approach:

> *"we start the dialogue early as possible in the process, and try to have a dialogue between the building owner, the consultants, the architects, engineering and maybe also the construction company to bring them in and then maybe people in our organisation. We have had a few projects in … our big development area, and good experiences from that".*

Although Jo's mention of contractors could be almost seen as an afterthought, the context of the discussion indicated that early contractor involvement was seen as important. She explains that if you take a design to a contractor and then discover it is too expensive to realise, then the design has to be changed, with associated time delays and costs. However, if contractors (and other stakeholders) are involved from an early stage they can flag some issues before much resources are expended on an impractical design. With different professions entities talking together, there is a greater possibility of discovering solutions that will be more cost-effective. Early involvement of contractors necessitates changes to the procurement practices which may prove challenging – this is particularly so with public tenders, where regulations will often impede such efforts.

However, for all the talk of early stakeholder involvement by the respondents, the lack of acknowledgement of occupant involvement in the design process indicates a particular shortcoming – even more so in the case of building renovations where occupants will be readily identifiable and where renovations may actually be carried out under occupation[129]. Relevant stakeholders from the design stage are presented in a power-interest matrix in Figure 44 below.

[129] Occupant involvement in building renovation design is a key component of the NewTREND H2020 project (2015-2018), the proposal for which drew partially from this research presented in this thesis.

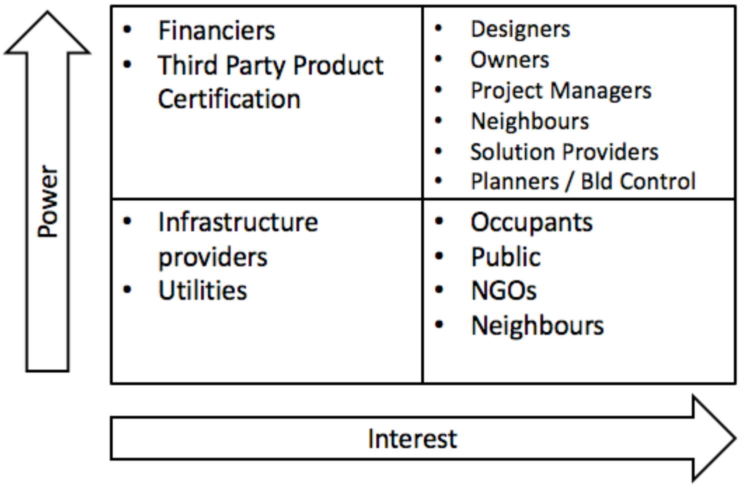

Figure 44: Power-interest matrix for design stakeholders (derived from Dunphy *et al.*, 2013a)

At various stages, different stakeholders may assume the responsibility for the targeted value outcomes of the project – which highlights the importance of establishing clear and unambiguous objectives for the project and ensuring the project structure and business models aligns the objectives of the individual stakeholders with the overall project. In the design stage, the architect or other designer is (or should be) the carrier of the clients' value.

Owners and other key stakeholders need to be provided with the maximum of information at the earliest stages of the process, enabling optimal and strategic decision making and the most effective use of financial and time resources – this implies early involvement. In current practice, many stakeholders may be reticent to commit this time, particularly if contract negotiations or contract terms and conditions may be influenced by the early involvement process. In other words, stakeholders may be reluctant to engage early if this could result in lower returns for them – if for example the early engagement led to changes in design and/or implementation which could mean a less significant role for some stakeholders. However, for the satisficing of value across the temporary multi-firm configuration (TMFC)[130] delivering an energy renovation project, such a step is invaluable. It is evident that stakeholders with differing priorities and knowledge bases may approach

[130] As outline on page 25, TMFC is a term used in this thesis (after Dunphy et al., 2013a) to describe the dynamic and transitionary value chains that coalesce into a form of project based organisation to deliver building renovations.

the same problem from widely disparate positions, for instance. This is frequently a function of training and perspective, as opposed to political or competitively motivated opposition. Early contractor involvement can help to make such perspectives overt, and can for instance, identify that there is a need for an owner or tenant representative on the project management team, to keep the priorities of key stakeholders to the forefront throughout.

The maximisation of value across the TMFC (not to even mention satisficing its component member's needs) presents a formidable challenge and is one that is particularly visible at the design stage. Individual contractors may be motivated to select solutions to maximise their own profits, or minimise their liability in terms of future involvement. However, such solutions may not necessarily align with the optimisation of lifetime performance for the project, or the maximisation of return to the long-term operators of the building. However, project objectives will for the most part depend on the priorities of the main stakeholders of the project, including building owner, the main contractor, and perhaps even financial backers (particularly where such funding comes with 'strings attached' – for example green investment funds). For the work of designers, this may mean that aesthetics may be prioritised in one project, while operating energy performance may be priorities in the next. As a service provider, the designer's work is therefore at the discretion of the main project stakeholder – which in most cases is the owner. Perceptions of risk may also emerge at the design stage – however, these are more related to professional and reputational as well as cultural aspects, as opposed to the more financially related risks, which first arise when considering project initiation.

6.4 Construction

Each building is unique and it follows that energy renovation projects are one-off, and generally non-replicable affairs. While the learning and skills may themselves be somewhat transferable, it is unlikely that the project approach, which worked in the case of one building, will work as effectively for another project without modification (although there is scope for some degree of standardisation and commoditisation within renovation activities as suggested below by Jans, one of the respondents). Any given project is likely to be structured around a mosaic of multiple contractual arrangements, on the whole forming the temporary multi-firm configuration (TMFC) for project delivery – while similar actors may be required in different projects, the same organisations will not necessarily be involved due to tendering requirements, timing issues and the inherent transient nature of contracting in the construction industry. The nature of the project TMFC is therefore of key importance.

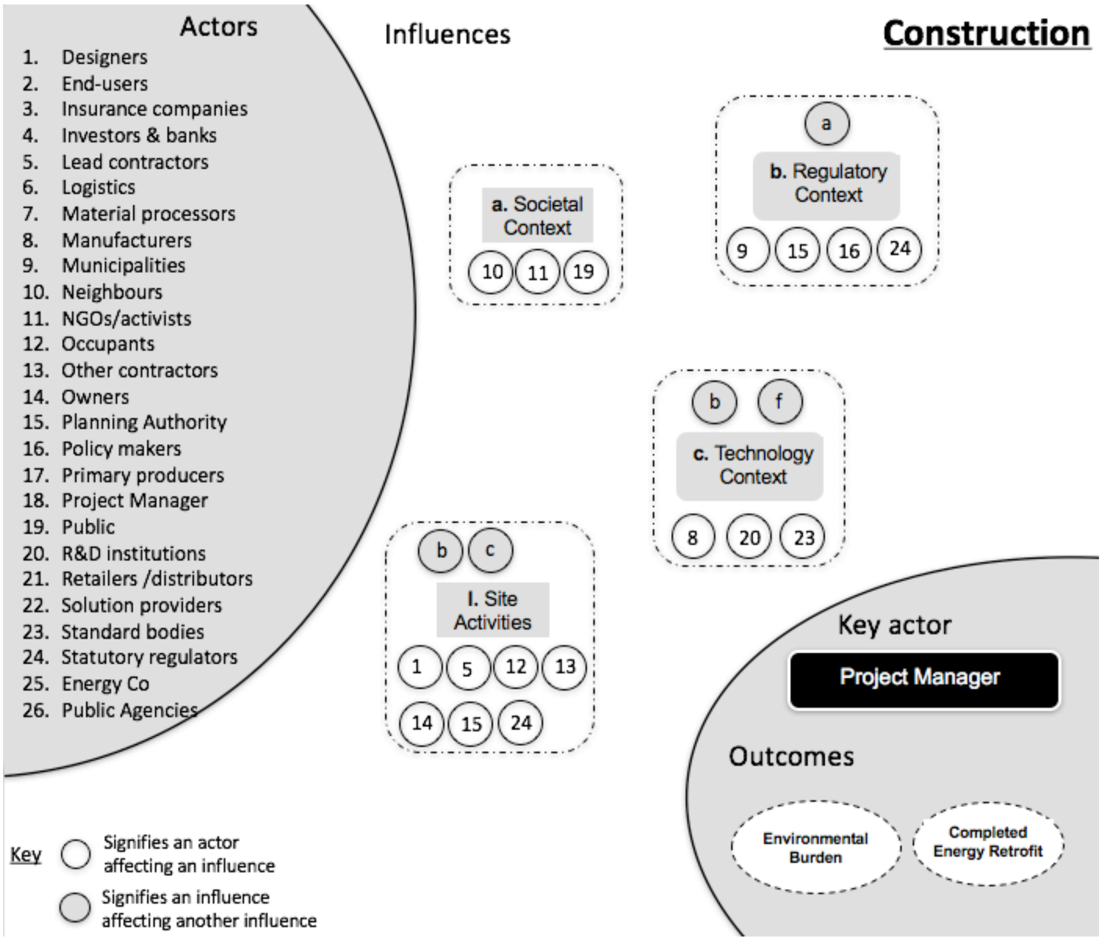

Figure 45: Actors, influences and outcomes associated with construction activities

Figure 45 above shows illustrative actors, influences and outcomes associated with the construction/implementation stage. The inter-organisational and inter-personal relationships within the on-site TMFC can determine to a large extent the level of success or failure of a project. Ideally this would mean building on existing relationships with participants in previous projects who have proven themselves would be recruited for the new project, however this is not always possible especially for public sector project – Eoin from an Irish public body explains:

> *"you can't use the previous experience as criteria to award a contract. If contractor 'B' has done a job for you before and contractor 'A' hasn't, you have to go with contractor 'B', even if contractor 'A' might do a better job, but that unfortunately that is the way of public tendering process".*

Eoin is indicating perceived shortcomings in the public procurement process, which while ensuring procurement is transparent may result in a less optimum result. While capacity to undertake work and track record in doing such work can be selection criteria, in public procurement it is not possible to simply choose a contractor because of a previous positive engagement with them (EU, 2014a, 2014b). This makes it all the more important that the criteria[131] used to select service providers are carefully designed such that suitable contractors are engaged

As some construction activities within a project may be sequential in nature, large delays and associated overruns of expense can occur when a contractor, who may simply be one of many on the project, fails to deliver on commitments. Many stakeholders spoke of the need for strong on-site leadership and co-ordination. The management of construction projects came in for heavy criticism from a number of interviews, for instance. In particular, respondents cited lack of quality control as a major weakness of the sector, and a problem for individual retrofit projects. Jans, a building owner representative from Denmark, commented:

[131] In this regard it is useful to note that Directive 2014/24/EU states that "contracting authorities are free to set adequate quality standards by using technical specifications or contract performance conditions" (Article 90, EU, 2014a).

> *"That's one thing with construction that I never understand, they don't make any quality control from case-to-case at all. They don't have, you would probably expect that in a very big company that if something was done as a procedure in one case, you would note it down and that it would be like an instruction (sic). No, in the company we have here and in other companies, and other companies also quite big companies, it's just project leader to project leader, that's all".*

In this statement, Jans is – perhaps quite reasonably – asking why construction is not more standardised and why lessons learnt from projects are not codified so this can be captured for future use. Of course, playing 'devil's advocate', one could also ask why don't building owners (particularly those with portfolios of buildings) become more informed, follow-up with construction companies, and take more ownership of projects.

Communications issues represent one aspect of this. The gap in communication between the design and planning stage and the actual construction stage can be problematic. Unless required by law or by contractual provisions, the designer may not always be on-site at all times to explain his/her vision, and or to correct and clarify on specific details of the plans. There is also an issue with differing levels of awareness, education and technical competency across stakeholders. Early contractor involvement provides one strategy to address this, as previously discussed, whereby expectations, practicalities and likely problems are addressed prior to project implementation in an open and explicit manner. TMFCs frequently work through informal communication channels, with associated benefits and challenges, which that presents. In the case of studied projects, problems were frequently identified in an *ad hoc* manner by site-visits from designers or owners during the construction phase, where expectations were perhaps communicated for the first time to contractors. This is a serious defect and owners/clients should not allow it to occur. In such scenarios, critical details can therefore be missed, mistakes can be noticed by chance or not at all and errors at earlier stages can lead to overruns and delays later on in the process. More formalised communication, including proper and correct design documentation, coupled with modern methods such as building information models (BIM) offers a potential solution. Olivier, a French architect strongly argues for the use of BIM in project communication, explaining:

> *"it enables us to discuss with the co-ownership to simulate several solutions, and enables us to communicate with the building engineers".*

As mentioned on page 177, there are a variety of co-ownership ownership model all of which involve shared governance and large numbers of 'owners'. Here Olivier is emphasising the flexibility of BIM models for communication with different stakeholders and for different objectives.

Stakeholders identified three key variables – time, cost and quality – that represent value, with cost frequently the prioritised variable. Time-related costs represent a significant part of the costs of renovation projects, with delays and leading to budgetary overrun and resulting in changes to ROI and payback calculations. The significance of costs is also seen in that monetary concerns also impact on many areas of the renovation process including but not limited to relationship of actors and in many case may dictate the nature of the project to be undertaken. Because of the focus on cost, sufficient resources are not always dedicated to the reduction of errors on-site (many of which could be prevented and/or resolved through improved communication and documentation as previously indicated), as companies who do so may risk losing market share to competitors who do not divert resources to management and control processes. The focus on costs also means that standard solutions will typically be used in preference to more novel solution, while this can be attributed to a form of risk management in many cases it represent a cultural disregard new knowledge development.

Client relationships and trust are reported as being important factors, although delivery-stakeholders and client-stakeholders offer divergent reports on how this manifests at the project level. For currently occupied buildings, the co-operation of existing occupants was highlighted as a key element for project success; in particular, the goals of the project needed to be appropriately communicated so that on-site activities could be contextualised, access for personnel arranged and disruption minimalised. The knowledge and awareness of clients is a key theme, which emerges, including issues of rebound effect, whereby the full potential of various projects is not realised due to increased expectations and experiences of comfort and thermal performance and in terms of wider cultural awareness of the need for energy saving. Certain works may also be possible in an occupied building, for example roof insulation, while the nature of use of the building may prohibit the selection of other options, for example internal wall insulation in a continuously occupied office building (although in some buildings with good planning and management it may be practical). Figure 46 below presents an overview of the power-interest matrix developed for the construction hub of activity.

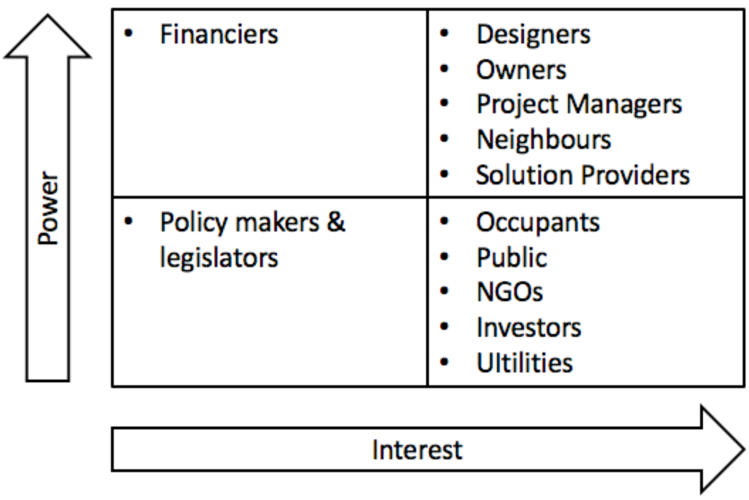

Figure 46: Power-interest matrix for construction stakeholders (derived from Dunphy *et al.*, 2013a)

Temporary multi-firm configurations (TMFCs) involved in construction and implementation of retrofit projects also display hierarchies of power and influence. Larger, more commercially active entities (including companies and joint ventures) may exert greater influence than independent SMEs or sole-trader contractors involved in the project for instance. For smaller companies, capacity is an issue for any type of project involvement. By definition SMEs will have less substantial portfolios of related work, which will make it more difficult for them to be selected for inclusion in TMFCs. SMEs may take part in 1-2 large projects per year, in contrast to larger companies who may be involved in hundreds. This determines the relative importance of an individual project for these organisations, but more pertinently creates an imbalance of power within the project delivery TMFC. These issues could be overcome by SMEs through: (1) the creation of alliances with other small contractors to provide a more competitive profile; and/or (2) developing relationships with large companies, identifying their needs and providing niche value-added services.

6.5 Operation

Figure 47 shows the Hub of Activities occurring at the operation stage, including a description of actors involved, the range of influences on these actors and potential outcomes. At this stage, the building occupants (and their representatives such as operators) are acknowledged as the lead actor and it is they who, through their behaviour and practices, that will greatly influence the level of success of a renovation project.

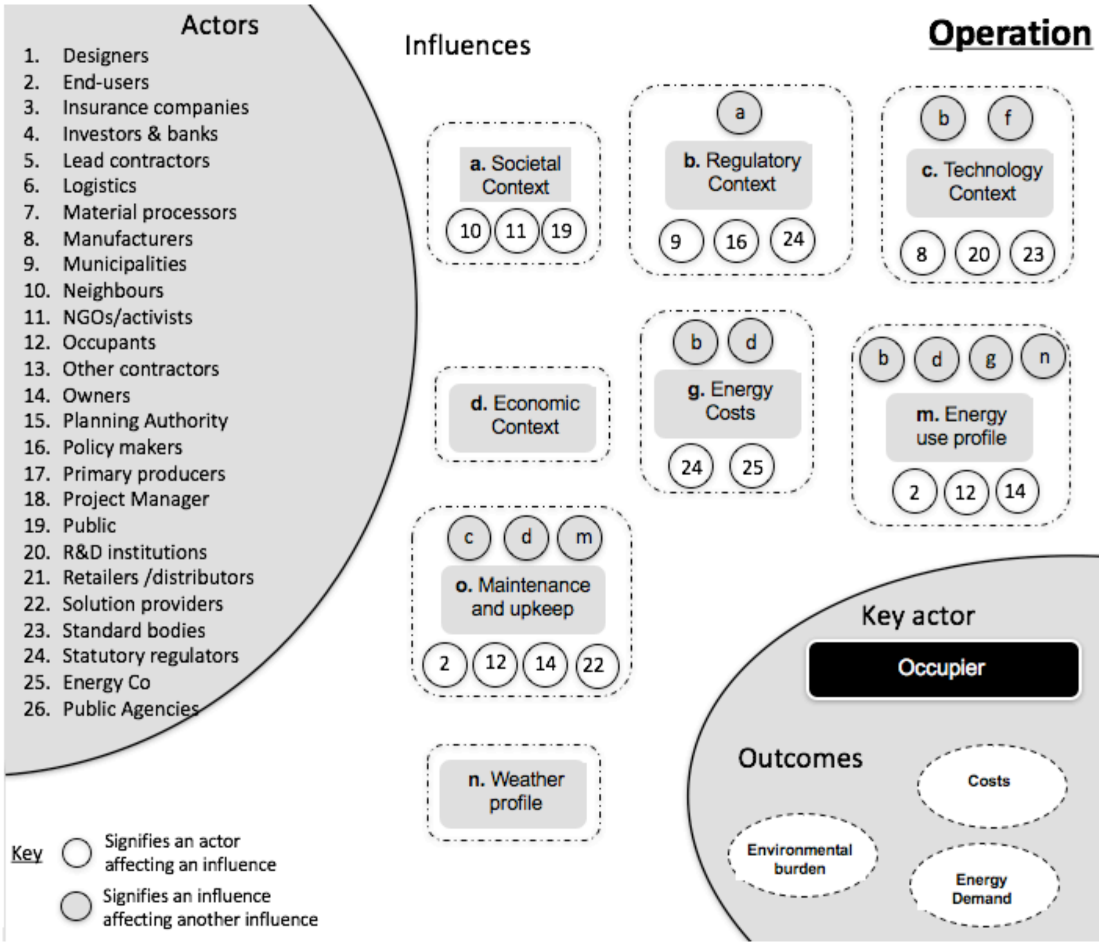

Figure 47: Actors, influences and outcomes associated with operation activities (Dunphy *et al.*, 2013a)

Split incentives and availability of resources represent key barriers during operation *e.g.,*

- For renting tenants, thermal comfort improvements notwithstanding, there may be no financial incentive to invest in a property if the asset enhancement of the retrofit project only enriches the landlord, and the benefit of reduced on-going operating costs is not shared.
- For owners and landlords, there is no incentive to invest in property if the tenant alone accrues the resultant cost savings[132].

Split incentives complicate a potential renovation project and in the first instance make it less likely to commence and secondly, if it is initiated make it less likely to succeed. For instance, Marcel a French developer speaking specifically about non-residential buildings

[132] While such property improvements may result in a more competitive market presence, it is not always the case that the market will reward such investment. This somewhat paradoxical aspect of the building market is discussed more on page 207.

says

> *"… we cannot do renovation projects, while in social housing we can do total operation, in tertiary[133] it is impossible because there is no profitability because of the split incentives, because we cannot work in occupied building".*

Although carefully implemented regulatory levers can serve to address the issue (including appropriately designed pay-as-you-save schemes), it remains a significant problem. Relevant stakeholders from this stage are presented in a power-interest matrix in Figure 49. Those stakeholders which are located in the upper-right quarter of the matrix have key roles to play in the success of renovation projects and it is not surprise that it is those projects where each of these can be suitably incentivised (*i.e.,* satisficed) that are most successful.

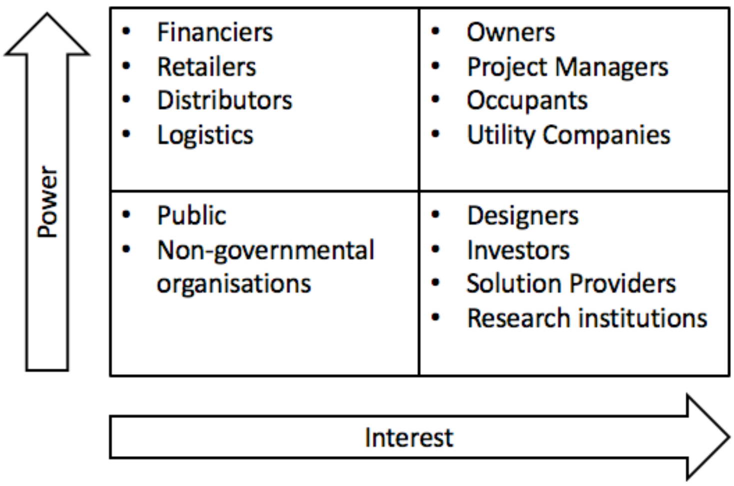

Figure 48: Power-interest matrix for operation stakeholders (derived from Dunphy *et al.*, 2013a)

To achieve the full potential of energy efficiency retrofit projects, user behaviour needs to be incorporated as a priority focus, alongside technical solutions. Behaviour aspects are important in a number of ways, in terms of user interest and awareness in energy use to begin with, and in terms of 'rebound' effects, whereby the full potential of various projects is not realised due to increased expectations and experiences of comfort and thermal

[133] Tertiary is another term used to refer to non-residential buildings such as offices and supermarkets.

performance and in terms of wider cultural awareness of the need for energy saving. While this maximising utility – what Jevons would refer to as 'maximising pleasure' (Princin, 2005, p. 54) – is often seen as a failure and something to be overcome, in some cases it perfectly reasonable outcome. For example, Aodh, an Irish policy maker observed that:

> *"… there are a lot of people now on fuel poverty[134], and when you do an upgrade in their building a lot of the investment goes into the rebound, probably 80% into rebound. If you compare this to a hospital where you do an energy upgrade there might be no rebound effect".*

While Aodh is still using the language of 'rebound' saying:

> *"certainly, in social housing … people will still spend whatever they got on energy if they can afford".*

Here he is framing it as something to be overcome within a project, he is inherently recognising that the fuel poor using some of the energy savings for increased comfort and perhaps raising it to acceptable levels is not inherently a bad thing. However, even accepting a certain amount of rebound can be positive in addressing fuel poverty, this does not explain the vast majority of the 'rebound effect'. Interviewed stakeholders described the 'behavioural jump' which was required along with a 'regulatory jump' to fully realise energy savings in the built environment. A first step in this is knowledge and awareness generation. Multiple stakeholders pointed to the fact that building occupants frequently had no awareness of the quantities of energy being used for space conditioning, of the cost of this energy, or of means to reduce it. Utilities described challenges with engaging clients,

[134] Fuel poverty is not just something that effect those traditionally perceived as less wealthy – it is a condition predicated upon a combination of high energy prices, low household incomes, inefficient buildings and appliances, and specific household energy needs (Bouzarovski, 2014). Governments often attempt to address fuel poverty through the provision of social support, which is misguided and perhaps even a little arrogant – improving the energy efficiency of buildings provides a more appropriate solution to the problem than fuel subsidies or income support (Goldemberg, 2012).

where (perhaps counter intuitively) a large proportion of customers have little interest in a conversation on energy costs. Ciara from an Irish electric utility observed:

> *“the majority of people ignore the bill when it drops on their mat”.*

She noted that payment through direct debit served to exacerbate the problem as:

> *“they can effectively ignore the bill, so they are not even looking at the minimum amount of interaction that you can have”.*

This separation of utilities from their customers and people’s consequential lack of relationship with the energy system has further potential implications with respect to energy consumption. This is in stark contrast with the reductions in energy consumption demonstrated by those with a close relationship with their energy supply such as energy prosumers and community energy schemes (see the example of the Scottish island of Eigg cited by Melville, Christie, Burningham, Way, & Hampshire, 2017). Difficulties with trying to engage in a broader discussion on energy efficiency are clear in the context of limited relationship with the energy system.

6.6 End-of-life

There is a strong lifecycle energy rationale for choosing to renovate building. As Power (2008, p. 4497) argues “*The case for planned large-scale demolition for energy reasons is greatly weakened when we consider embodied energy as well as energy in-use*”. However, there are of course embodied energy implications associated with the end-of-life management within renovation projects also – in terms of both the construction and demolition (C&D) and other wastes arising during the renovation and of the eventual decommissioning and end-of-life management of materials and equipment added to the building during the renovation.

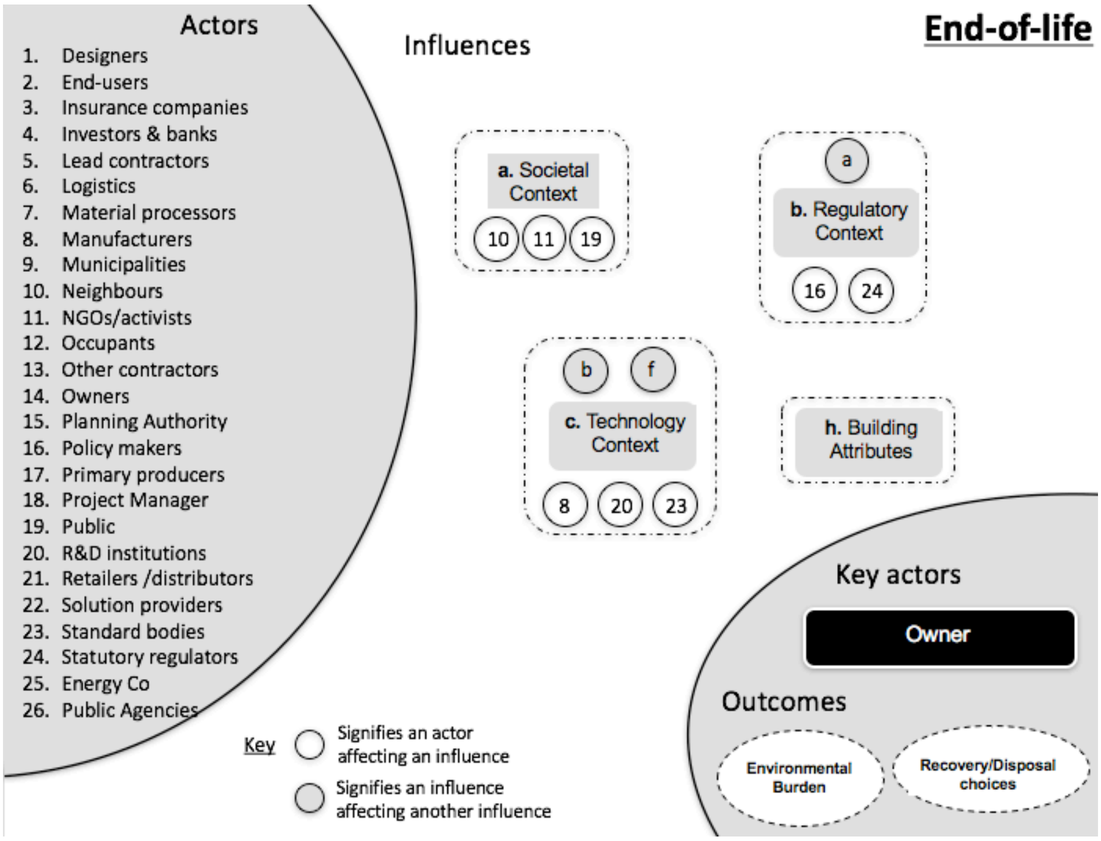

Figure 49: Actors, influences and outcomes associated with end-of-life activities

Figure 49 shows the Hub of Activities occurring at the end-of-life stage, including a description of actors involved, the range of influences on these actors and potential outcomes. The lead actor is the owner who will make the decisions on recovery and disposal choices which will directly impact the environmental burden – including the associated embodied energy. Relevant stakeholders from this stage are presented in a power-interest matrix in Figure 50.

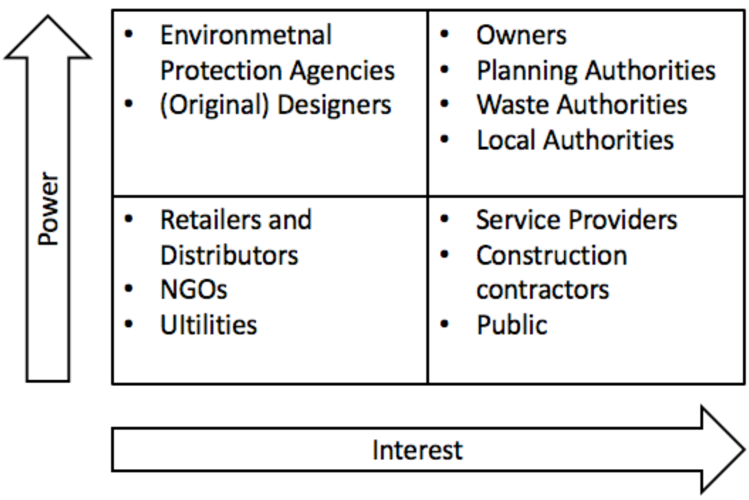

Figure 50: Power-interest matrix for end-of-waste stakeholders (derived from Dunphy *et al.*, 2013a)

The end-of-life stage is something that is often overlooked in considering construction and not surprisingly it did not feature prominently in the interviews. This is itself informative and demonstrates the (often) disconnect between the construction activities and consideration of how to deal with the resultant waste. It highlights an area that would benefit from further research.

The long periods of time separating renovation projects from further renovation or later demolition works can be substantial, up to 100 years in some cases. This presents challenges for the maintenance and transfer of value across the building's lifespan, including the intergenerational transfer of liabilities and the use of externalities in project costing and business models. The appropriate application of the polluter pays principle, and the remuneration of pro-environmental choices are necessary to address this value time-horizon issue. This will require public policy choices by governments and as mentioned before on page 185, the built environment, and particularly building renovation is a good example where environmental policy integration could be implemented to great effect.

6.7 Review of chapter

This chapter sought to present some insights on the *Hubs of Activity* model which emerged from the analysis of the interview. Building on the interview data a mapping exercise was carried out for each *Hub of Activity.* The mapping exercise detailed the actors, influences, and outcomes associated with, and identified the key relationships within each hub or stage. Subsequently, this information was used to develop illustrative power-interest matrices reflecting the relationships of the key stakeholders at each stage.

Chapter 7 which follows expands on this initial exploration, deals with the key findings from the in-depth interviews as illustrated in Figure 38 on page 166.

7 Key findings

"Look beneath the surface; let not the several quality of a thing nor its worth escape thee" – Marcus Aurelius

This chapter comprises a presentation and discussion of the key findings arising from the thematic analysis of the respondents' interview transcripts. Five principal themes emerged from the analysis, as outlined in Figure 38 on page 166, namely: (i) *Knowledge* (including: awareness, education and training needs, research and innovation, networking); (ii) *Marketplace* (including: opportunities, customers, innovative products, competition, market expectations, impact of financial crisis); (iii) *Finance and business planning* (including: organisation, project delivery model, business model, risks); (iv) *Project* (including: motivation and drivers, barriers, objectives, technical issues, approvals and permits, end-user behaviour, Stakeholders); (v) *Society and policy* (including: legislation and policy, social issues, environmental consciousness, cultural differences).

7.1 Knowledge

- Knowledge gap and related skills shortage with respect to renovation activities within construction industry.
- For those seen as having a skills shortage, there is perceived little, if any market (or other) incentive to upskill.
- Differences observed between countries in their openness to novel approaches and overall attitudes to innovation.
- While some countries were happy to be leaders in innovation others seem to place more value in transfer of proven knowledge.

Text box 1: Highlights from respondents' views on 'knowledge'

7.1.1 Perceived knowledge gap and skills deficit

There was widespread agreement among the respondents that education and training are a significant issue. In many cases this reflected a feeling that the construction industry generally requires upskilling to meet the needs of sustainable construction (as discussed below, some indicated upskilling of craft trades, while other suggested engineers and other professionals required updating of their knowledge). Sven from a buildings research centre in Sweden suggested there was a:

> *“need to increase the basic education or background of people in construction companies because it’s quite low today”.*

This demonstrates a belief that the standard of the construction workforce is not at a desirable level – the inference from Sven was that it had been better in the past. Eva, a Spanish manufacturer of smart meters, offered a related point, commenting:

> *“there is a general lack of technical expertise in the construction sector”.*

While use of the phrase ‘technical expertise’ could be interpreted as referred to engineers and other professionals in light of his business, it was apparent from the context that this was meant as a general point across the construction trades and professions. For others, the issue was more focused on renovation specific skills, *e.g.*, Hamish, a sustainability officer in a UK local authority noted “*skills (shortage) is a big problem”* for building energy renovations.

This lack of skills capacity in the industry was evident also from a number of comments about putting projects together. Jans, the representative of a building owner in Denmark, for instance, argues that:

> *“the general problem in the construction industry, the contractors take longer that they are supposed to”.*

Here, Jans is observing that the contractors are not as efficient as they should be. This comment, considering it was made during a part of the conversation relating to training and education, inferred a lack of skills capacity. A possible reason for this deficit may stem from society's (and by inference) clients' unwillingness to pay for the required education and training required for the sector.

This skills deficit is reflected in the comments of Áine, an Irish architect, who said:

> *"I've found that any builders I have worked with - most of them when they start a project and haven't done a low energy building"*

although she did go on to comment

> *"… but generally, they get it, they are willing to learn".*

John, a British main contractor explains that:

> *"We do use the same (people) at the moment because we have a system that we developed with these people and it's easier to keep going with that".*

The reference to "… easier to keep going ..." and the tone of the sentence, implies that John is not particularly enamoured with the current sub-contractors, indicating instead that he is settling somewhat for the existing contractors, due to a lack of confidence in other offerings in the marketplace. A similar, if more nuanced, point was made by Áine, the Irish architect, who said:

> *"I would try to keep the tender list to people who I know are good, there are guys I would go back to again".*

Here, Áine's unstated suggestion is that many of the prospective tenderers may not be 'good'. However, notwithstanding the need for upskilling in the sector, there was a feeling that the required training and education was not (yet) being delivered. Firstly, there was some questioning of the educational offerings and whether they were meeting the needs of the renovation sector. Rupert, a project coordinator in the building controls office of a German city administration commented that:

> *"architects are educated to build new and then it's quite easy to design the perfect building, but most buildings are built already and it's very different".*

This highlights an often-unstated fact that nearly all training and education is based on the ideal of a new build – practitioners are then expected to adapt their methods to suit a renovation project. Rupert is challenging this approach, observing that they are very different propositions.

7.1.2 Reluctance to upskill

However, persuading people to attend training emerged as an issue. Morgane, from a German construction regional training centre found that their experience was that people are reluctant to take training or educational offers, commenting:

> *"... that's the tricky thing, people won't come (to training on renovation) if there is no obligation".*

Her compatriot, Rupert, agreed about the lack of uptake and posited that it could be due to the strong construction jobs market commenting:

> *"… at least in Germany we have the problem that the craftsmen have so much to do, there is so much construction going on that they don't have really interest in special education, because every hour they sit in a course*

> *they can't earn money, so there has to be big motivation for such a course that they can even earn more per hour afterwards".*

Here, Rupert is saying that there is no market incentive for people to attend training or education programme on energy renovation, as the cost incurred in obtaining training are not rewarded by the market, and because they can continue to get work without specialist training on renovation related topics. This perceived education and training deficit suggested by a number of respondents, implies a market failure – prospective trainees simply are not rewarded for completing such training.

7.1.3 Attitudes to innovation

Paul, a research manager in a Danish non-governmental organisation found the construction sector to be slow to accept innovation, commenting:

> *"... as I mentioned before, I mean the building traditions and so on, that could be room for more innovation, there could be more, the different actors, or entrepreneurs or architects, could be more – let's give it a go, we will try to approach it this time, they are a bit conservative".*

Paul's comment that they (those involved in the construction sector) "*are a bit conservative"* was a deliberate understatement, the context of the statement and the tone of voice implied that he felt he was reasserting a truism, and that the qualification 'a bit' was meant for effect. This cautious approach was also noted by Miguel, a Spanish developer, who said:

> *"In general, the architects in Spain are not really open to new strategies and new technologies, innovations... some architects even if they say they believe in energy efficiency, once in the project they do not like to introduce modifications, and new technologies, as it modifies a lot the project".*

A degree of frustration is apparent from Miguel's comments, he is implying that some architects only pay lip-service to energy efficiency and do not follow up with actions. This is a little unusual, in that it would be more common to see the roles reversed *i.e.,* an architect making this comment about developers. Notwithstanding the cautious nature of the construction industry mentioned above, innovation was considered to be particularly important for the future of energy renovation sector by a number of the respondents. For example, Sven from the Swedish research centre suggested that:

> *"… subsidies and the investment from the public sector should be directed towards increasing the study level of the construction sector. More, industrial PhDs is a better word to use, should be directed at increasing the competence level in the business. I really believe more industrial PhDs and if more Horizon and FP7 projects could support PhD's in companies, that would have a huge impact on the long-term".*

Here, Sven is not explicitly talking about addressing the skills level of the day-to-day construction worker or even construction professionals, but rather a knowledge gap and suggesting that the level of innovation in the sector would be increased by improving its research capacity.

Thomas a project manager in a Danish industry association highlighted that innovation networks are playing a significant role in his country saying:

> *"Denmark has, all-in-all, 22 innovation networks and they are all funded from the Agency of Science and Innovation".*

He continues explaining that:

> *"It's free to be a member, the only thing you have to pay is your time, we expect you to be active in the network, but it doesn't cost a fee to enter".*

François, responsible for energy efficiency projects in a public agency, mentioned an analogous resource (if a more top-down approach) in France when he said:

> *"I forgot to tell you about other potential interesting actors, it is what we call the platform Batiment Energie Grenelle, that are entities with technical characteristic that enables innovation of a lot of actors, there is around 10 in France. They are setting up networks and have technical realisation, a bit like a resource centre. To give technical elements to practical actors in the field".*

Sven from Sweden also suggested:

> *"If you have people in your company that are accommodated to do research and that have some thinking about how to acquire knowledge, then that should simplify the innovation process with companies involved".*

Yet, there is a feeling that some intellectual work is not valued. Olivier, an architect complains that:

> *"The cerebral work in France we consider it as free. We pay the concrete, we pay the insulation material and other things but what is not visible we are not ready to pay (for) it".*

While he was without doubt thinking of his own role as part of this 'cerebral work', he was referring also to wider innovation activities.

In contrast to the Germany and the Nordic countries for example, there was little explicit discussion of innovation across other countries. In Ireland, for instance, the emphasis was more on demonstration projects. Peadar, a representative of an Irish construction industry group, spoke of the value of using exemplars:

> *"if you can take one pilot like that and move on, the pilot in terms of the training of the workers, getting the third level institutions involved, getting the likes of SOLAS[135] involved ... construction companies can then develop in terms of the skills gaps that are there. And all of this can create a domino effect very quickly, once the model is in place, once it has been tested and once people see it working".*

Peadar is referring to demonstration of technologies and approaches, that have been proven already, most likely in other countries. While his comments reflect an industry that is open to novel methods and approaches (albeit those that have been verified elsewhere) – the emphasis on tried and tested approaches does perhaps indicate an aversion to risk-taking. While some of this make be linked to economies of scale, it is noteworthy that innovation appeared in the conversations with respondents from countries of similar size. Jo a municipality manager spoke of the willingness to innovate and to support innovation in Denmark:

> *"We are willing to use Copenhagen as a green lab for companies and partners to work together with us".*

It would therefore appear, that the absence of innovation in the discussions is more likely linked to business culture and wider socio-cultural issues.

[135] An tSeirbhís Oideachais Leanúnaigh agus Scileanna – Irish Further Education and Training Authority

7.2 Marketplace

- Renovation market seen as a fast growing relatively large sector.
- View that market did not reward energy efficiency activity sufficiently.
- Suggestion to bundle projects together to get scale and mitigate risk.
- Vulnerability of the construction sector to a credit crunch was raised showing a need to decouple renovation market from wider construction market so that it is judged on its own merits – new business models needed to clarify distinction and show potential returns.

Text box 2: Highlights from respondents' views on the 'Marketplace'

There is acknowledgement that the building renovation market is quite substantial, growing and as such potentially represents an area of activity with substantial return. However, some concern was raised by the interviewees as to whether it rewarded energy efficiency renovations and whether it did so sufficiency *i.e.,* from the perspective of those undertaking such renovations.

7.2.1 Size of market

Rogier, a Spanish contractor spoke of the potential large addressable market for building energy renovation, observing:

> *"… in Europe, the building's life is quite large, very few new buildings are going to be constructed, but in the retrofit sector, a lot of buildings are going to be retrofitted".*

Rupert a building control officer from Germany agrees, saying:

> *"… in Germany by now, more than 50% of the building market are done in existing buildings, not in new buildings".*

Whereas, Rogier is alluding to the size of the addressable market (in qualitative terms), Rupert is actually quantifying the relative size of renovation activity in comparison to new build construction. It is apparent that renovation is a significant activity and moreover that the level of activity can be increased. The market for building renovation would appear to have significantly grown over the last number of year. According to Jörg, an executive from a major German building materials manufacturer active across Europe, the market for energy efficiency related materials has grown substantially.

> *"... Yes, the growth is faster in this segment than in any other segment ... twenty years ago that was probably only a small plant within the organisation but it has grown significantly over the last ten years it been almost equal to the other products that we sell".*

Jörg is letting us know that products specifically targeted at energy efficiency of buildings has grown from a low base to the point where they account for around half of revenue – it is telling that he is not bashful in sharing this information, which implies that both that this aligns with their wider business strategy and that it is something that they believe will reflect well on the company.

7.2.2 Potential returns

Notwithstanding the previous comments on the growing renovation and energy efficiency market, Jean the director of a French public-private renovation initiative strikes a note of caution. He argues that:

> *"… the big construction companies nowadays they prefer to put their operations resources in other more profitable services like parking or highways, but not really to do external wall insulation for collective housing building built in the 60s".*

In saying this Jean is making the point that not all construction activities provide the same financial return. However, these two views of the market are not necessarily contradictory, as Jean is referring to a very specific, almost a niche level renovation activity, while Jörg's comments on sales would of course reflect the wider renovation market. It does suggest however that 'the market' may be concentrating renovation activity on the so-called hanging fruits, the easy wins, and not addressing less exciting, perhaps less profitable components of the building stock and that renovation activities are similarly been concentrated on easier projects with more assured outcomes.

7.2.3 Risk reduction through bundling

There would appear from the above section, to be an element of 'cherry-picking' of opportunities in the market, which obviously will not deliver the mass levels of renovation required to meet the challenging targets, which public policy expects the built environment to achieve. To this end, Jo, a Danish municipality manager suggested that there is a need to develop economies of scale for a viable retrofit marketplace, saying:

> *"We have to find a means where we can have a business model where you try to bring more projects together. What we are doing now is making a map of the city of all buildings, so we have a map monitoring of the buildings related to types/standard, energy standards but also owners, so we can bring the same kind of owners with the same kind of buildings, with the same kind of chances related to retrofit together".*

Here, the Danish municipality is taking the initiative to create a knowledge base to enable and facilitate bundling of smaller renovation projects together to create portfolios of projects, which can be then be marketed as investment opportunities[136]. Mathew, Kromer, Sezgen, & Meyers (2005, p. 1328) suggest "*a demand for standardized, portfolio-based approaches to energy efficiency projects … (could lead to) … the benefits of commodification*". Such commodification would reduce price, increase efficiencies and quality, and offer greater assurance of results. Jo was referring to a conventional approach *i.e.,* bringing the "*same kind of owners with the same kind of buildings with the same kind of chances related to retrofit together*". There is however, potential in the aggregation of energy renovation projects to allow for mixes of project sizes, types and risks, and a form of portfolio-based risk management such that the risk profiles of the portfolios can be balanced, facilitating funding of renovation that otherwise may be unacceptable to the market[137] – this is not uncommon in other areas of investment and could have value in the renovation domain.

7.2.4 Reduction in activity due to economic issues

Miguel from Spain, explained how the previous Spanish construction boom significantly delayed the implementation of energy efficient buildings:

> *"In Spain, very few sustainable buildings have been developed. There has been much marketing and publicity, but actually very few have been developed. The reason is because during the last years there was such a boom in real estate activity that there was no need to differentiate with sustainability or energy efficient building".*

The subsequent market crash has resulted in a price war, of which Miguel says:

[136] Sweatman and Managan (2010, *pp.* 29–37) forward one approach to creating portfolios of renovation projects in their 'Aggregated Investment Model'.
[137] Such portfolio-based approaches however do reduce the benefits that accrue from standardisation and specialisation – the risk of losing these benefits can be minimised through careful bundling.

> *"The problem is that the market is pushing the companies to decrease the sale price of the apartments; thus, previous models have been distorted".*

and

> *"Today, having so little demand, the product needs to have a strong focus on costs and price".*

What Miguel is reporting is a paradox of the building market: during a property boom, there is no need to differentiate buildings through energy efficiency renovations – as it is a seller's market and buyers are chasing too few buildings, and in a post-boom slump, the market does not reward such investment – in a buyer's market the premium for energy efficient buildings may not be sufficient to repay the cost. It would appear that (market-driven) renovation activities require a Goldilocks' market context (which of course only ever arrives very fleetingly, and so in reality no matter whether the market is up or down, there is little motivation for investment). The Spanish market place is not expected to recover for a number of years, Mateo, a business development manager with an engineering consultancy, estimates:

> *"we (will) have to wait 2 or 3 years in Spain to see the recovering of the economic crisis and to see the construction market recovers".*

While Miguel believes it will take a little longer:

> *"We are waiting for the sector to reactivate in 3 or 4 years".*

This in turn has led some Spanish companies to internationalise their operations, Mateo, a business development manager with a Spanish engineering consultancy commented

> *"Knowing that we have to wait 2 or 3 years … [] … we have to focus on other markets".*

This illustrates both the mobility of construction businesses (*i.e.,* by their nature they can move locations) and the problem which may arise for the resultant reduction in market capacity.

Of course, a similar downturn took place in other countries, for example the post-2008 interlinked banking and personal debt crises served to reduce demand for energy efficiency projects in Ireland. They reduced the industry capacity to provide exemplar or flagship energy efficiency projects, and reduced demand from customers for sustainability motivated initiatives. Eoin, a project engineer with a public-sector owner of buildings commented on the downscaling of projects:

> *"… the big projects, for example this building would have been one of the last big projects that we had, this building has solar panels, biomass boiler, natural ventilation. Those type of projects, where you can put in all those things are gone".*

The almost wistful tone in Eoin's comments, indicates that he is waiting for the day in which such projects return. There is almost a subtext in Eoin's statement that he associates the importance of project with the number of different types of interventions, rather that the mix of solutions that are best suited to the building and its users. Roisin, an energy retrofit manager at a care home also observed the effect of the financial crisis on renovation activities, observing:

> *"… whoever, might have been industry leaders, but are now a shadow of their former selves, not through anything to do with their retrofit models, but it's impossible to separate the two, if the construction industry crashes, the retrofit industry is going to crash too".*

While this need not be the case Róisín is making a point that the renovation sector is not considered separately from the construction industry as a whole, and that the downturns in the construction market as a result of credit restrictions, directly impact all construction companies even those focused on renovation. A differentiation is needed to persuade the market to break this link – in this respect, novel business models like energy performance contracting (Pätäri & Sinkkonen, 2014) have a role to play.

Peadar, a contractor agrees saying:

> *"… the ability to focus on them (energy efficiency issues) has been hampered utterly by the financial constraints that both the public and the private sector find themselves under at the moment".*

Here Peadar is observing that during the financial downturn, prospective customers simply did not have the money for renovation projects – given the fiscal constraints at governmental level, and the restriction in the availability of credit for both businesses and householders – within a flow of credit construction will not occur. A response from Séan from a waste exchange initiative, perhaps encapsulates the change in the construction market caused by the financial crises:

> *"… now a lot of the construction people on our databases are gone out of business so it's a hard area to target at the moment"*[138].

This rather bleak statement from Séan paints a picture of an industry in crisis, which is perhaps not an overly harsh view of the construction sector in the immediate aftermath of the financial crisis. Áine, an Irish architect suggested:

> *"… most builders, they kind of want to do things right - most builders don't set out to build bad buildings – they will if they are allowed and if*

[138] Séan is informing us here that many of the companies on his database were the smaller more vulnerable businesses, indicating perhaps a lack of engagement with larger businesses.

market conditions are pushing them in that direction – but as long there's enough carrots and sticks most builders do want to do the right thing".

This response perhaps indicates that although she is explicitly stating that construction companies 'want to do things right' in terms of sustainability, Áine really knows that it is not that simple and that incorporation of sustainability into construction requires incentivisation and penalties. Sven, from a Swedish buildings research centre agrees, commenting:

"… there always a few people that want to be the front runners, but most people frankly don't really care that much. They don't want global warming, but they don't want to pay with their own money".

The inference from such responses is perhaps that a market-based approach on its own will not be successful and that there is a role for policy interventions, including but not limited to regulatory measures.

7.2.5 Socio-cultural aspects

Socio-cultural and socio-economic aspects play an important role in markets. Hens from a German construction research organisation, in some part playing up to national stereotypes, suggests that Germans are reluctant to take on debt of any sort and this consequently affects type of supports instruments that would be successful, saying:

"... I think the people don't like the low interest loans, the normal house owners because they don't want to take the credit ... they like to have more the direct cash".

Although, not directly stated there was the implicit comparison with other countries (including Ireland and Spain), in which householders are believed not to have such reservations[139]. This was not intended as a criticism of these countries or their people per se, rather Hens was making the point that, approaches to building renovations must be tailored to suit the target markets.

Anders, a retrofit designer raises the collective ownership structure of many houses in Copenhagen, saying:

> *"Many of the buildings in Copenhagen is co-operative owned. You know it used to be private rental but after the renewal process or just if the owner doesn't want to have the mess about it, the owner sells it to the tenants and they create a cooperative who will take care of the building and I think they are still in the old part of Copenhagen it's the most common ownership".*

Such co-operative ownership models, are very interesting as they can both provide facilitate and impede renovation activities depending on the particular circumstances and the management and decision-making structures of the co-operatives. Anders suggests that the experience of Copenhagen in collective ownership models might be useful for other countries. This is a further example of the need to create bespoke approaches to building renovations not only for individual market but also for market segments as suggested by Staniaszek *et al.* (2013, p. 22) for example.

7.2.6 Move away from project-based activity

While not a new phenomenon, an interesting aspect of the construction industry is its moves towards industrialisation. In Sweden, Sven from a building research centre explains that they are working:

[139] This difference in attitude to debt is borne out by Chmelar's (2013, p. 4) observation that '*Between 1995 and 2007, the overall stock of household debt in the EU expanded almost three times, while in countries with significant real-estate expansion, such as in Ireland or Spain, the debt expanded as much as six-fold*'.

> *"... to help the industry to be more industrial like, to try to get the long-term production cost down, and this is huge benefit. If we can make the construction more industrialised it has a huge transformative potential, because then you can compare companies easier to each other, you'll get a true EU market for construction firms, and all of these have huge efficiency benefits and that will drive down the costs of what we are trying to achieve".*

By moving away from a project based delivery mode towards industrialisation, Sven is inferring that standardisation of product *i.e.,* the buildings, is required, which in turn would facilitate standardisation of the various tasks involved in construction (albeit, site-specific issues may reduce the level of industrialisation achieved). His compatriot, Elsa, a project manager with an energy research agency agrees, observing the move towards prefabrication:

> *"We in Sweden I think, a trend to prefabricate is growing. Especially when you come to wooden structure, you produce your building parts in an industry and then transport it on a truck. You build it and then you need to assemble it, put the walls and roofs together. And that's growing in Sweden, we do this quite much. Also, the university was one like that. I think it's an efficient way of producing".*

While industrialisation does not necessarily have to mean prefabrication, it is an increasingly preferred option for other reasons. In addition to standardisation, such offsite production provide a number of other benefits including reduction in waste (and associated embodied energy and GHG) by up to 40% (Monahan & Powell, 2011, p. 180), improve control of quality, weather independence, speed of construction, *etc.* This movement to industrialisation aligns very well with the scale of the renovation[140] required over the coming decades and also speaks to the commoditisation of the energy efficient project, suggested by Mathew *et al.* (2005, *pp.* 1327–1328).

7.3 Finance and business planning

- Effects of the post 2008 financial and banking crises still being felt.
- While there is a technical understanding of what needs to be done – this has not translated into a business understanding. This is proving challenging to those active in promoting renovation activity.
- Novel financial instruments such as the German KfW green loans show that if supports are structured well they can work (contrast will the ill-fated UK green deal scheme).
- There was little talk about unsuccessful renovations – this lack of openness indicates that respondents were open to sharing good results, but maybe not those that do not flatter so well.

Text box 3: Highlights from respondents' views on 'Finance and Business Planning'

7.3.1 Access to finance

Not completely unrelated (at least temporarily) to the financial crises, although of course a long-standing problem – access to finance emerged as a significant impediment to renovation activity[141]. Ciara, a policy advisor from an energy utility in Ireland says:

[140] Of course industrialisation of energy renovation of existing buildings will inherently be a tougher challenge that for new build construction

[141] Interestingly Maria an Italian banker does not mention access to finance as a barrier rather she suggests that the barriers most inhibiting energy renovation and retrofit projects, are the "*lack of a national or regional regulations*" and the end-users' cultural sensitivity and awareness towards renewable energies. This could be construed as Maria being disconnected with societal realities, but more likely she is thinking from a different perspective – in her worldview, there are people with access to funding who are not implementing renovations and that is what she is perhaps trying to explain. Those that do not have access to funding, from her perspective, do not come into the equation. It is not a social judgement, but just a factor of the world in which she is situated.

> *"...the bottom line, certainly when we are talking to customers at the moment is – I don't have the money upfront to pay, even though I know, yes, it makes sense for me to do that work, I don't have the money there to do it.*
>
> *Five years ago, I might have had savings in the bank, but those savings are gone, or I might have been doing that instead of squirrelling away money, but now instead of squirrelling away money I am struggling just to pay the property tax, and whatever else".*

Ciara is relating the financial constraints that many prospective customers faced in the aftermath of the financial crises post-2008, this is an understandable concern but one which will have to be overcome, not least because of the uncertain politico-economic context facing Europe and the world today. Sweatman & Managan (2010, p. 46) however, from a macro level, argue that such barriers are all the more reason to engage in energy renovations, saying:

> *"In a world struggling to recover from financial crisis and endeavouring to confront climate change, an investment in increased energy productivity must be a priority as it returns cash to homeowners, improves liveability, reduces emissions and invests in long-term national value streams".*

The challenge then is which mechanisms to use to finance such activities. This importance of financing (even for public organisations), was emphasised by Eoin from Ireland, who said quite openly:

> *"We wouldn't have done the [energy renovation of a public building] project if we hadn't received the grant funding".*

Eoin is opening a window in the workings of the public sectors – it is not monolithic, the grant funding which enabled the project came from another state agency and yet if they had not been successful for this competitive funding the project would not have progressed. Jean the director of a French public-private renovation initiative agrees on the importance of financing saying:

> *"I wanted to say that one of our problem is to structure loan that are as low as possible, otherwise the payback time explode. That's why the Green Deal[142] doesn't work in UK for this reason. And it works in Germany because they could have a loan for 1.5% over 25-years".*

Jean here, focuses on the cost of loan financing arguing that the interest rate is key. It is notable, notwithstanding the discourse about alternative financing mechanisms that he focuses on the traditional loan product. Alberto, an Italian manufacturer reminds us:

> *"... it is worth considering that financial institutions act within a regulatory framework that obliges them to earmark credit only if the borrower can show enough capacity to repay its debt and collateral guarantees".*

Alberto is once again pointing out that the financial status of prospective renovators can be an impediment to obtaining finance for projects, particular since many houses that most require energy renovation and those most likely to less advantaged and not be eligible for such funding. Achieving the level of renovation activity required to meet our energy efficiency and GHG emissions targets required a range of funding approaches to ensure

[142] The Green Deal was a UK government scheme which Rosenow and Eyre (2016, p. 141) described as an *"innovative pay-as-you-save energy efficiency finance mechanism for the able-to-pay market to deliver retrofits at a large scale without the need for public subsidies in an age of austerity".* The scheme proved unsuccessful and (DECC, 2010b). Launched in 2013, the initiative did not prove successful and was closed following in 2015 with such 15,000 green deal deals.

that the entire addressable market is covered. Peadar, an Irish contractor asks a broad question:

> *"are there green financing models that could work? I think that is going to be the key, when we break that I think the market will really take off".*

Peadar seems to be agnostic as to the form by which financing is delivered, just that the finance is made available to viable projects and the unspoken view that this should be done as soon as possible.

7.3.2 Cost effective renovations

There appears to be an element of improvisation to energy renovations. Practically everybody is in agreement that it is a good thing and that it must be done. However, amongst the respondents there are some differences the specifics *e.g.*, what should be done? Who should do it? How should it be financed? *etc.* Technically, there is a great deal of knowledge on what needs to be done and which measures need to be prioritised for energy efficiency of the building stock. However, the renovation market is not just a technical arena and there is an element of truth in the idea that the renovation market is searching for answers to these questions at the same time at delivering building renovations. Michael a Danish energy consultant suggests that:

> *"… a lot of money (is being invested) in the housing and building sector without any cost-effect evaluation without any evaluation whether it is cost effective, sustainable".*

In this case Michael is not arguing about financial return but simply asking are the best solutions being selected for renovation – he is in effect questioning the planning of renovations. He is substantially saying that money is being thrown at a problem, without exploring the effectiveness and efficiency of the solutions. This casts images of key actors in the renovation domain frantically searching for opportunities to spend money that has been ear-marked for building energy efficiency. This idea of improvisation, is further supported by Ciara from an Irish utility who reports that Irish policy makers:

> *"have pulled back from calling it pay-as-you-save, because they are concerned that some retro-fit scenarios won't actually save enough to pay, particularly they are worried about this rebound effect you know whereby you take comfort in the fact that you now have better insulation or a better boiler or whatever, and you don't actually save as much as you would have been projected".*

This too conjures images of policy makers running fast to keep ahead of a fast-changing context. Both Michael's and Ciara's response illustrate an immature policy context, changing societal and market expectations and a marketplace that is far from stable, that is unsure of itself and that is searching for a business template that will just work.

There is a trend towards third-party investment that holds (some) promise for greater adoption of energy efficient measures. Jean, a director of the public-private renovation initiative in France comments of the use of third-part financing:

> *"either we achieve a very ambitious energy efficiency and we can do a third-party financing or if it's not so ambitious we don't do the third-party financing. Because it is public money we will do the third-party financing only when there is high ambition in terms of energy savings".*

In some French regions, the value of 'green' aspects of buildings, is beginning to have a very strong influence on the total asset value. François the manager of energy efficiency projects with a French public body, comment of results emerging from energy performance contracting studies comments that the 'green value' of a renovated property can be:

"much more that what other studies have shown" and "can have more that 25% of value".

François is indicating the opportunity for novel financial instruments based on property value, bundling a number of such projects into attractive investment portfolios can open the door to the third-party investments mentioned by Jean, while the increasing asset value within the portfolio should act to minimise the cost of finance.

British respondents were unsurprisingly disappointed at the take-up of the so-called 'Green Deal' in the UK (which was still in operation at the time of interviewing). At that stage, it was obvious that it had, to date, not made much of an impression in the market place. Philip a building standards officer was beginning to become sceptical about the programme, saying:

"... I sometimes question how active it is ... we've only had one or two applications with that presently. I sometimes question where it's at".

While, Hamish a local authority sustainability officer expressed his surprise at the lack of interest:

"... I thought there would be people lining up at the door (for Green Deal projects)".

Hamish is expressing not just surprise but an element of frustration that there had not been more applicants for the programme. There is an element of a technocratic mind set in his response, in that he simply cannot understand (or perhaps even accept) that people did not take up a renovation scheme that made perfect sense from his (professional) perspective.

The promise of the UK 'green deal' programme as also recognised in other countries – for example, Ironically, considering the subsequent failure and abandonment of the Green

Deal, Jörg from a German manufacturer expressed admiration for the UK scheme saying:

> *He hadn't "seen a programme or a financial approach or financing system as accelerated as the Green Deal in any other country … outside of Germany here and there, but nothing as advanced as the UK".*

Notwithstanding the interest shown in the UK Green Deal programme from some German interviewees, The UK (and other) respondents looked with jealousy at some of the German initiatives. For example, Alice, a retrofit office in a UK local authority commented:

> *"... I know we looked quite a lot at Germany and their model with the KWF bank, a type of a green deal. The main difference is that their interest rate was 2.5% or something, a lovely interest rate. I think, Germany seems to have it well worked out".*

Alice has reduced the UK and German programme to their basic interest rate and while that is of course a very important part of the picture, it is telling that a retrofit officer focused this particular element of the scheme.

Jean, from a public-private renovation initiative reported on an even-better sounding interest rate with the French zero-rate eco-loan, but he did see an opportunity to improve this financial instrument, saying:

> *"We would like the eco-loan become a collective eco-loan. And furthermore, we would like to borrow on behalf of the co-ownership, in order to take the risk from us. Because the problem of the co-ownership is the heterogeneous individual situation, with the young that just took a debt, etc. Imagine tomorrow on behalf of the co-ownership we can take*

> *an eco-loan on 20 years at 1% and it doesn't cost more to the state, we are the oil king".*

The idea of a collective eco-loan is not only useful for housing co-operatives (or co-ownerships as Jean refers to them), but also offers a means for collective renovations of separately owned properties, which in some ways feeds into the ideas of bundling renovation projects together as discussed on page 214.

There was only a small amount of discussion by the respondents about actually instigating renovation projects. Hamish, a UK local authority project manager, explains how they plan renovation on their building stock:

> *"… we tend to review our buildings once a year, and see where's our worst users, or our worst performers, and start to highlight opportunities within them for the next year, or future years, depending on how they rate".*

Hamish is explaining that the approach they take is based on addressing the so-called 'worse performers' and while this is admirable it perhaps is a little simplistic as it does not take into account: potential energy savings, cost effectiveness, mass roll-out of particular solutions, learning from experiences, *etc.* All of which could result in a more effective and efficient renovation programme.

Michael from Denmark explained that even for their public-sector organisation decisions of renovation were down to money:

> *"We do look at payback, if a project has a payback of 25 years, it's not going to be looked at. Something between 3-5 years more or less, we would look at it. I know in the private sector people are probably only*

> *looking at something with a 3-year payback or less. We might extend ourselves to 5, but that is as long as we would go".*

This is quite a short timeframe in the context of the lifespan of buildings and even more so, considering that public organisations are in a position to take long-term views. Michael is admitting that even for them financial return was central to decision-making. There was an inference that getting value for public monies was a concern, perhaps even an ethos, that was promoting such decision-making. This demonstrates that the public organisations which owns such a large proportion of the building stock in Europe need to develop more holistic evaluation criteria and transparent decision-making process. If the public sector does not lead in taking longer-term views, it is unlikely that a significant amount of private sector building owners will do so.

7.3.3 Information and support

Learning for the experiences of others is often a good motivator for energy renovations *e.g.*, we saw previous Peadar, a representative of a construction industry group, speak of the impact of demonstration projects. In this context, Roisin, a retrofit manager with an Irish Care home expresses their willingness to share experiences:

> *"There are other organisations looking at what we've done but we can't really bring them in to show them this project until we've good figures to back it up".*

Interestingly, by saying they are waiting to have 'good figures to back it up', Róisín makes it clear that while they are willing to share success stories, they may not be as open to sharing other results and lessons. This lack of discussion of projects that have not gone to plan means that there is perhaps an over-rosy picture being communicated to prospective building renovators – this is turn means that there may be a deal of scepticism about such initiatives. To provide information and support decision making, François an energy efficiency manager explains about the energy efficiency 'one-stop-shops' which has been launched in France:

> *"the 'one-stop shop' will be a sum of measures that will be designed at municipality level or group of municipalities, or when there isn't at department level or perhaps regional level. And they will launch project call at regional level from September-October".*

François is referring to services, which offer a single contact point for all the services which may be required for an energy renovation project from the planning stage right through to implementation and occupancy. The idea is that in return for a fee (sometimes waived) that they assist people through the planning process, advise on solutions and give guidance on funding schemes.

7.4 Project

- Agreement that all work should be coordinated on achieving renovation objectives – indication that this may not be entirely heartfelt.
- Comment that certain technologies (insulation for example in Germany) were given too much prominence in energy renovations – whether through policy or the public discourse on the topic.
- Motivations for the project were varied and illustrated the need for bespoke business models for renovation project.

Text box 4: Highlights from respondents' views on the (renovation) 'Project'

7.4.1 Objectives

The need for integration in planning and delivery was suggested as key in achieving project objectives. Aodh, an Irish public policymaker, for example was sceptical of achieving greenhouse gas emissions reductions, if all work on the project is not coordinated towards this objective, saying:

> *"They all understand that they have to achieve this. So, there is no point in the architect trying to say 'I'm trying to keep my carbon emission down', when the structure engineer doesn't take up that part … or the service engineer".*

This issue was confirmed and reinforced by his compatriot, Eoin a project engineer from an Irish public body who answered, in a response to a query on solutions considered for a project:

> *"We're mechanical & electrical engineers. Glazing and insulation is a matter for our colleagues in architectural services. So, we don't look at them at all"*

He further quipped:

> *"That's an ecumenical matter!".*

While the response taken at face value might be thought to reflect the usual demarcation of work within project – the subsequent quip[143], and the body language used, intimated that not only Eoin did believe that reducing greenhouse gas emissions was not 'their concern', but hinted at a degree of scepticism as to its importance.

There is a suggestion that perhaps insulation has been over emphasised in energy renovations heretofore at the expense of other measures. Rupert a German building control official says:

[143] This quip originates with an episode of the TV comedy show 'Fr Ted' wherein it was used as a mechanism for avoiding difficult conversations.

"... so, in the public discussion at least the focus has been very much on insulation, but insulation is not everything, and, I mean, the laws, the policies level, they are addressing more or less in the right way, but in the public discussion, you find that this is always about the insulation".

Rupert intimating his feeling that the insulation industry is dominating the discourse on energy efficiency in Germany – notably he does not blame lobbying as he feels the policy context is suitable, rather the wider business and social context. The ease of communication of insulation benefits no doubts plays a big role in its prominence, it is simply easier to explain that many other solutions, however there was an inference that the market power of the insulation companies may be coming to bear, influencing the supply chain to promote their products.

7.4.2 Barriers and challenges

Anders, a Danish retrofit designer, feels that the construction sector suffers from poor management, which can lead to poor results:

"I think actually its training and management, but construction is always very … they have generally very poor management because management are just self-made people and then you have this culture, especially in Denmark I don't know how it is in other countries, if its construction, it doesn't have to be high quality and perfect".

The quality of an energy renovation is key to its success and poor quality will not only lead to poor results but only to poor uptake of renovation projects. Anders is implicitly expressing his unease at the work practices within construction, his reference to the 'culture' of the industry is telling and infers that he believes it is not a positive influence to say the least. But poor management is not limited to just construction companies,

companies with portfolios of buildings are often run by people with limited technical knowledge and while their general business management make be good they often do not understand buildings and their workings. Rupert from Germany, makes the point that:

> *"...housing companies are often run by economists or business administrators who don't have anything to do with energy efficiency of course they have engineers, the question is whether do they believe them, or not, do they listen to them".*

While, Jans from Denmark says that:

> *"a lot of real estate investors in Denmark, that's people who have inherited them, or people just have a lot of money but who aren't interested in real estate, just have to place the money somewhere. The municipality has a real problem with talking to them, they have actually no interest in the buildings".*

Rupert is referring to professional administrators running large companies, *e.g.*, the housing companies which supply a great deal of Germany's rental market; Jans is taking about what might be describe as the 'accidental landlord', amateurs who have found themselves owning property – in both of these cases the people making the decisions have very little knowledge about buildings and construction. This creates problems in communication and can lead to poor decision-making.

Rupert, a German building control official pointed out the lack of integrated thinking apparent in some renovation planning, points out that:

> *"... one of the stakeholders is the [building] heritage department, we are sometimes a little bit outside because people come to us only after they*

have drawn up their plans, and then they are sometimes disappointed when they are told, well you can't do this and that, you should have come earlier, we would have told you that in the first place, it would have saved a lot of work".

Rupert is to referring to a quite specific example, but one which typifies the lack of forethought and planning that often goes into building renovation projects. Another example of integrated thinking is future proofing of buildings. Hamish in the UK, for example reported:

"… if we are building new buildings, we are tending to, if it's an office, we build the kind of office that can be adapted into something else … so all the technical functions into a new building and that can become anything".

Here Hamish is talking about making more adaptable buildings that can be repurposed without major works. This type of thinking can also be applied to the renovation of buildings but with respect to the future use of the building as detailed by Hamish, but also in planning energy interventions *e.g.*, Ruarí from Ireland commented:

"… It's an essential maintenance job, as it's turned out. If you knew that that space would be reconfigured in 6-months, you might just do the patch job, but if there's no plan for the foreseeable future, you may as well do a decent job on it".

While a 'patch job' as described by Ruarí will not provide the efficiencies required of a full renovation, holding off on a full renovation until the required physical reconfiguration will avoid a wasted renovation and the associated lifecycle cost, energy and GHG implications.

Future proofing technological choices is also important, particularly with the quick pace of technological innovation evident in the market. However, Ruarí, an Irish building manger pointed out delays which can arise from trying to respond to advancements in technology:

> *"You can run into problems too where you might have to re-apply for planning permission. It might be significantly different to the extent that you might have to reapply".*

Here, Ruarí is recounting how the discovery of a new technology led to a decision to change solutions for a project because it resulted in great efficiencies, however the new solution required a new planning permit which would have delayed the project for a considerable time and so the original solution was used, notwithstanding its lower performance in terms of costs, energy and greenhouse gas emissions. The lesson from this account is to conduct a thorough solution search as part of the preparatory process.

7.4.3 Motivation

For many, an overwhelming driver for energy renovation, as with any investment, will always be financial savings, in this case typically communicated in terms of 'energy savings', although there are signs that reductions in greenhouse gas emissions, colloquially called as 'carbon emissions' is becoming more important. Hamish, for example, from a UK local authority says:

> *"(his) role is to try (to) essentially reduce … initially to reduce the energy consumption, but it's expanded to more carbon ... so carbon reduction is the main driver in our work".*

Eoin, a project engineer in an Irish public-sector building owner reports the inverse, with the focus originally on climate impact and latterly directly on energy savings. He reports:

> *"(they were) originally motivated by an attempt to reduce energy use in buildings from an environmental/climate change point of view and we were looking at climate change, global warming, CO_2 increases etc. We were installing these systems to reduce energy consumption from that perspective… The government is now focused on reducing energy consumption, rather than reducing carbon dioxide".*

Fred, an energy engineer in a UK Local Authority comments:

> *"(the motivation for their energy renovation projects stems) from the targets to cut carbon emissions, really that's the biggest driver".*

In this statement, Fred is, perhaps unintentionally, informing us that although greenhouse emission reduction is stated as an objective, the real motivation is meeting government established targets. This aligns with Eoin's point above about public sector organisations being driven by government policies and particularly so when there are performance metrics. Interestingly, Eoin also reports that

> *"(their renovation activity) was never ever motivated by cost. Cost is a happy co-incidence, that a reduction in-energy use will reduce your utility bill cost".*

For some, the desire to reduce greenhouse gas emissions arose from ethical or religious roots – these can be particularly important drivers as they are strong motivators. This further indicates the importance of understanding the stakeholders involved in particular projects. For example, Clive, a UK developer made the point about a particular project:

"there is a community here that was founded on the principals of ...

sensitive dialogue with the intelligence of nature".

It was obvious for Clive's comments that he was searching for appropriately respective terms to discuss the spirituality of the community he was working within. While, he did not necessarily share or even understand the beliefs of the community, his respect was apparent and the outcome of these beliefs was an approach to construction and buildings that was in keeping with Clive's ethos.

7.5 Society and policy

- Growing interest in life cycle perspective of good and services
- Suggestion that material going into buildings now may be problematic in the future when they reach their end-of-life
- The human factor within building is of increasing interest – although sometimes still framed in rationalist terms *e.g.*, that building users need to be educated
- Energy reductions appear to come from non-plug load components – our gadget filled modern life (which itself a by-product of a narrative, pushed by corporate interests that consumption equates with happiness) may be an emergent issue.
- Building regulations perceived to sometime inhibit new technologies.

Text box 5: Highlights from respondents' views ' Society and policy'

7.5.1 Public discourse

Hens, from a German construction research body suggested that there may be an orchestrated campaign playing out in the media, against energy renovations commenting:

"... one main problem I think is that there is very different information in

the … especially in the media ... misinformation ... and I think there is a

> *lobby of people or associations behind that who don't want the standards to be strengthened".*

Hens is suggesting that there are a group (or groups) of people lobbying for building regulations not to be strengthened. He is inferring although it remains unsaid that interested parties *e.g.*, developers, housing companies, landlord associations *etc.* are influencing public discourse and in so doing attempting to influence policy-makers to retain the current building standards. This is an interesting counterpart to his compatriot Rupert's view (discussed on page 232) that the German public discourse on renovation was been dominated by the portrayal of insulation is always the answer to energy efficiency in buildings. It is of course entirely possible that both views are correct, but what is more interesting is the fact the there is a public discourse on building energy renovations, something that is sadly lack from many countries.

7.5.2 Environmental consciousness

For some, the renovation of the building itself posed environmental issues. Olive, a UK ecovillage resident saw a disconnect between 'energy efficiently' and sustainability, remarking:

> *"(a lot of effort on buildings was to make them) energy-efficient, yes – sustainable, no. Lots of stuff going on with people putting solar panels on their houses, communities and farms that are building windmills but people still don't really think about the extra building of the house, and they still build things that are really shit, really rubbish materials and they ship them from the other side of the country and you get people that build very environmentally friendly houses but half of the stuff comes from foreign countries all around the world so".*

On a similar line, Sven from a Swedish building research centre, raised an interesting dilemma, observing that the material going into buildings now are going to be problematic in the future, saying that:

> *"…talking about a life span or 35-40 years for the good material, much of what's going into the building now, will not be recyclable, or is not currently recyclable, so in 35 to 40 years we are going to have a major issue unless we come up with a way of recovering the materials or the energy that's within that".*

Kristin a project coordinator at a major German building exhibition, agreed with Sven and commenting on the growing interest in the life cycle perspective of good and services, she says:

> *"… the discussion of life cycle analysis is really growing and of recycling of the products you build with, not only in new construction but also in retrofitting; there is a huge problem to recycle all these plastics and combined materials".*

A related concern is the impact of renovation on the many heritage building, which are to be found in European cities. Although the necessity for the energy retrofit of heritage buildings is acknowledged, it is seen as a sensitive and problematic issue especially for brick buildings which are completely altered by external wall insulation. Rupert the building control official from Germany complained about the loss of heritage caused by some renovations to older houses, commenting on historical houses specifically, he said:

> *"... they are all getting covered with Styrofoam-like external insulation which on a brick wall is the most devastating, because it's just gone afterwards".*

Rupert is questioning whether such building should be subject to the same standards and treated in the same manner as more modern buildings. Accepting that their energy performance must be improved, he is specifically asking the question:

> *"what technical solutions are available to improve the energy efficiency of historic buildings especially brick buildings".*

While Rupert is specifically addressing brick building, a similar question could be asked about many other heritage buildings types and components.

For others, sustainability takes a more social dimension. Rupert from Germany makes the point that in displacing coal use, energy renovation can have positive social impact, saying:

> *"… in South America, where the coal is coming form that we are firing here in (the) power station, I mean the rainforest is cut down and the native people are expelled from their land without any compensation so sustainability also includes social fairness, besides the environmental aspect of it".*

7.5.3 Social dimension

While Anne, an ecovillage resident in the UK makes the points that much of the work that our community does on energy renovations is primarily for the pubic good, with financial return secondary, commenting:

> *"… the folks who invested on the whole, invested for the good of the community, for the good of the whole, for the good of the experiment, while still anticipating that their couple of thousand or certainly their couple of hundred thousand, would be returned in due course".*

Here Anne is emphasising the community solidarity as much as it environmental ethos, she goes to stress the environmental motivation of all that they do:

> *"We sourced almost everything from responsible companies that had responsible environmental policies, that were re-growing the timber that were renovating the clay pits when the tiles were extracted or whatever, so we looked at what the sources of all the materials were as clean as possible, the paints were all eco paints, the floor covering we all – basically those houses should compost nicely".*

The clear message that she is trying to convey is that we are good people, doing good things, for good reasons. While nothing is as simple as that, the ethical element of sustainability as mentioned previously, can be a significant driver not just of individual renovation projects but also of public policy and of increasing relevance societal norms.

The human factor of energy renovation is an area of growing interest, particularly human behaviour and how it effects the design performance of energy interventions[144]. A common refrain, which emerged from the interviews was the importance of people's behaviour to the success of energy saving initiatives. Marcel, an energy efficiency director with a French property developer stressed the importance of the human factor when he said:

> *"while nowadays we really don't care about the building but what's important are the people within the building. The energetic problem of France today is the behaviour of people living in the building".*

Philip, a UK building control officer suggests a related but separate problem, he believes

[144] These human aspects of energy are being considered in far more detail in the ENTRUST H2020 project (2015-2018), which is exploring the human factor in the energy system, and the proposal for which drew from the research described in this thesis.

there is poor knowledge about the use of new technology being retrofitted into buildings during renovations, observing:

> *"... I think a lot of homeowners, we've seen it, is they are getting pieces of equipment put into their house, and these super-efficient boilers, they are getting different types of heating, they are putting in heat recovery sometimes and a lot of them just don't know how to operate them".*

Adam owner of a philanthropic firm from Denmark suggests a mixture of aforementioned problems saying that:

> *"… one should be extremely careful about how the users actually operate the building. … They don't care. They don't have to pay the bill themselves, they don't care. It will mean that most energy conservation projects eventually will fail in their initial aim".*

The answer to these two related perceived problems of errant behaviour and inability to use new technologies is often seen (in a rational behaviourist perspective at least) as education and training. For example, Adam the Danish philanthropist referring to set points for heating argues:

> *"that is one of the aspects that we need to address, to educate the user. Why did we invent the sweater in the first place?"*

While, Maria from an Italian bank, speaking about new energy networks suggested in addition to determining the best means of delivering the energy to customers opined work is required to understand "*how to 'educate' them to this new way of managing energy*". While occupants, no doubt could benefit from some advice on the use of new and unfamiliar technology, the reverse is also true *i.e.*, designers and solution providers could benefit from understanding how people live their lives, what they want from their buildings and how they use technology.

While the point on education and training mentioned by a number of respondents is not without merit, but with regard to building renovation it does need to be challenged in some contexts. Provision of information and equipping people with appropriate skills greatly contributes to delivering normative change and creating new cultural norms in society (see e.g., Assadourian, 2016). However, in the context of these discussions the focus was on people's use (perceived misuse) of renovated buildings, there is an underlying perspective – that experts know best how to design building renovations and that people just need to be informed how to use them correctly. This again has some truth to it, in that new technologies and equipment often require instruction on use – but the missing element in all of this is an acknowledgement that building users are the experts in their lives and that their lived experience is typically overlooked in building renovation design – leading to the perceived need for training.

When considering building energy consumption and energy renovations, the natural inclination, at least in the European context, is to concentrate on the building fabric and the integrated heating, ventilation and air conditioning systems (HVAC). However, the so-called plug load is gaining attention. Adam, owner of a philanthropic firm in Denmark describes his building's intelligent building management, which restricts the switching on of lights "*you simply cannot turn it on if there's enough daylight*". He further explains how approximately one-fifth of the building's electricity consumption is saved by linking a so-called kill-switch to the facility's intrusion alarm, commenting:

> *"when I leave from here, everything switches off. There are a few fridges and so on, and one or two switches in each room, so for example those architects, made these complicated renderings and their computers just*

> *sit there working overnight and they had to plug them into these special plugs, because otherwise, they, everything is killed off".*

The consideration of plug-load is not overly common but it is of growing significance. As discussed on page 97, operational energy consumption of buildings is decreasing as buildings are made more energy efficient. Disaggregating this operational energy, it can be seen that these reductions are principally coming from the non-plug load components and so increasing the relative significance of the plug load demand. As increasing quantities of energy consuming devices find their way in everyday life, plug load is destined to increase even further. Kaneda, Jacobson and Rumsey (2010) observe for example that plug loads account for *c.* 15% of total consumption of energy in a typical California office building, but that once HVAC and Lighting performance is involved plug loads increase to over 40%. Considering plug load energy demands combined with a comprehensive energy renovation would seem to offer a holistic energy efficiency strategy for a building.

Opportunities for district-level energy initiatives[145] were noted by some of the respondents, particularly those from central and northern Europe. Michael, a Danish energy consultant, highlighted Copenhagen saying it was:

> *"an example of what you can do in a metropolitan area for example all the larger buildings are interconnected in district heating grids which make sure that you use all the surplus and cheapest energy before you start the boilers".*

The presence of the district heating and cooling present significant opportunities for energy efficiency at the district- and city- scales in Copenhagen. However, in such context, there is a need for greater scrutiny of the relative performances of proposed individual standalone

[145] Indeed renovation of building in a district level context is topic of the NewTREND H2020 project (2015-2018), the proposal for which partially drew from the research described in this thesis.

technologies over the centrally provided infrastructure.

7.5.4 Regulatory context

Building regulations can be quite restrictive for novel technologies and approaches, as can be seen from the comments, Philip, a building control officer in the UK. He praised a former building standards' manager who he explains:

> *"basically, allowed (an eco-village) to be what it is now because he took a leap of faith for them, and give them assistance at the time, to allow them to grow these things. At that time, it wouldn't have been in the standards, but now they are very much there".*

Although the standards have since being updated to take account of these specific techniques. It is made abundantly clear that this was a departure from normal behaviour and was entirely based on the personal inclinations of an individual, rather than an accommodation of innovation. With this in mind, Philip's unease at the apparent influence of industry in the development of planning and building control regulations is most understandable. Philip observes:

> *"... the industry has quite a lot of say in where these policies go, which I find quite interesting".*

The 'quite interesting' remark at the end of the sentence, informs us that he is a little wary of their involvement and sceptical as to their motivations – there would seem to be a conflict of interest, it would be obviously in the industry representatives' interests for the standards to favour products that their supply, which would in most cases favour the status quo.

The regulatory context has a large role in shaping the market. In Germany for instance, the effect of regional 'rental tables' (*mietspiegel*) was raised by Hens, a project leader in a German construction industry research organisation. Under the *mietspiegel*, rents are controlled and only certain increases are permitted, which obviously impacts on the ability to recover the cost of improvements through rents. Hens explains:

> *"... (mietspiegel the term used for) rental table literally translated would be Rental Mirror, so it mirrors the situation, and that is produced by figures on the economic aspect - various properties of house contribute to the rent, and this one, additionally all the quality, the energy quality is adding to these items to these qualities to these properties that are respected in this".*

The desirability of amending such tables to reflect energy consumption, carbon emissions and potentially other environmental metrics was mentioned. This is a classic example of a split incentive, an issue that was raised by other respondents, for example, Bjørn, from a Danish research establishment asked the question:

> *"depending on the type of building, if you have tenants of a sort, how can you motivate, how can you legally tell them to pay a little bit more and also for them, will it be a good solution economically?".*

In Spain, another issue to thrown up by regulations, the legal inability of third parties to access energy consumption data has led to mistrust and created some doubts about the honesty of the ESCO service. Eva, an owner of a smart meter company explains:

> *"A group of energy professionals, managers and directors, started to analyse electricity bills and feel they are been scammed by the utilities. It has been happening in Spain since years, but why? In Spain, utilities are*

the only ones with the detailed information of the energy consumption of their clients".

7.6 Review of chapter

This penultimate chapter comprised a presentation and discussion of the key themes arising from the analysis of the respondents' interview transcripts. It discussed the five principal themes emerged from the analysis, namely: (i) Knowledge; (ii) Marketplace; (iii) Finance and business planning; (iv) Project; and (v) Society and policy.

The next and final chapter draws together the key findings from the research, examining their significance and implications for satisficing building energy renovation activities. The limitations of the study are reviewed, recommendations forwarded, and suggestions made for the further direction of research

8 Discussion and conclusions

"If all the economists were laid end to end, they'd never reach a conclusion" – George Bernard Shaw

This final chapter draws together the key findings from the research, examining their significance and implications for satisficing building energy renovation activities. The limitations of the study are reviewed, recommendations forwarded for the increase of renovation activity, and suggestions made for the further direction of research in this area.

8.1 Satisficing renovations

As discussed in Chapter 4, the creation and distribution of value is a fundamental activity of business. In section 4.3, Business Models were introduced as the "*rationale of how an organization creates, delivers, and captures value"* (Osterwalder & Pigneur, 2010, p. 14). This section builds on the knowledge developed in earlier chapters, on building renovation value chains, to forward use of the business model approach and related tools as a means of satisficing building energy renovation activities.

8.1.1 Which value propositions?

At the core of a company's business model are its value propositions, described by Lanning and Michaels (1988) as products and services assembled and offered to meet customers' needs. This represents a straight-forward trade, where the focal company provides something desired by a customer in return for payment[146]. In building energy renovations, in additional to thermal comfort, the traditional value propositions sought by clients are two interlinked, but distinct metrics:

- Financial return *i.e.,* the net financial benefit of the project accruing from lower operating costs. This is particularly important where project principles pay for energy;

[146] The captured value for the focal company is almost always monetary *i.e.,* companies provide value propositions to customers in return for financial reward. This has the effect of a tendency among some to conflate captured value with money. However, this does not need to be, nor is it always the case.

- Energy savings[147] *i.e.,* consumption of energy avoided due to the renovations. Increased energy efficiency is an important value in its own right including: (a) meeting regulatory requirements; (b) contribute to greater rental and/or sales value; (c) potential associated monetary value *e.g.,* tradeable white certificates (Bertoldi & Rezessy, 2008)

More recently, there is a growing interest also in the avoidance of GHG emissions through such projects. While such emissions are strongly related to energy consumption they do not have a direct relationship [148]. Analogous to energy 'savings', avoided GHG emissions have an inherent value for many project principles including: (a) meeting regulatory requirements; (b) adherence to corporate sustainability policies; (c) facilitate access to 'green' funding;' (d) rental and sales market differentiation, *etc*.

Business models are inherently focused on a particular organisation's operations, the challenge in satisficing building energy renovation activities is that, as discussed in Chapter 5, such activities are delivered by the aggregate work of an extremely varied group of actors. Chapters 6 and 7 illustrates that these actors bring multiple perspectives to projects and the challenge is to associate their objectives with that of an overall project – or in the language of business models to align value propositions. Construction projects are realised through one of a variety of project delivery methods. These delivery methods basically act as framework, with a strong contractual basis, within which the various activities discussed in Chapter 5 take place. The following section presents an overview of project delivery methods which directly govern the relationship of the key actors associated with renovation projects, and will so influence attempts to align value propositions.

8.1.2 Project delivery method

Renovation projects, as with all construction projects, are delivered by the collective effort of various entities that coalesce into a form of project-based organisation, with

[147] Other prominent value propositions include *e.g.,* thermal comfort, staff productivity.
[148] Although related, energy consumption and GHG emissions are distinct performance metrics – as discussed in Footnote 2 on page 2.

relationships of varying degrees of formality (Dunphy et al., 2013a). This thesis has termed these project-based organisations temporary multi-firm configurations (TMFC). The composition and nature of a TMFC will be directly influenced by the project delivery method selected for a particular project. Within construction, a project delivery method[149] is the name given to the means by which a building owner provides for organising and financing of a project. This method chosen for a particular project will to a great extent determine the nature of the business models for the associated businesses. The following project delivery methods (and their variants) are examples of commonly used arrangements (more detailed descriptions are included in Appendix 4 on page 325):

- Design-Bid-Build (DBB): contracts with separate entities for the design and construction (traditional approach to construction);
- Design-Build (DB): design and construction services are contracted from a single provider;
- Design-Build-Finance-Operate (DBFO): contract awarded to design, build, own, develop, operate and manage an asset for a set contractual term;
- Build-Operate-Transfer (BOT): contract awarded to finance, build and operate a facility for a stated period of time, following which it is transferred to the grantor;
- Lease-Develop-Operate (LDO): existing assets leased (or sold) to contractor who renovates and operates the asset for a set term, following which ownership reverts.

Project delivery methods, such as those outlined above and discussed in more detail in Appendix 4, can be thought of operational frameworks, around which the various actors involved coalesce into a TFMC. As discussed on page 25, component-businesses relate through procurement and subcontracting arrangements of various degrees of formality.

[149] Also known as 'product delivery model' or 'product delivery system'

As illustrated by Figure 51 below, a TMFC can be thought of as comprising a core of formal bilateral and multilateral contracts which organise key actors to implement the desired project delivery method. Outside the core, is another layer of formal contracts (including sub-contracts, sales agreements, *etc*.), which enable the key actors to deliver their contractual obligations, while yet another layer of informal arrangements (including for example mercantile transactions) exist which enable the realisation of the project. As an approximation, the closer one moves to the core the more difficult it is to substitute for goods and services – in other words, as would be expected typically the more important attached to a service or product supplier, the greater the likelihood that their relationship will be formalised through contracts.

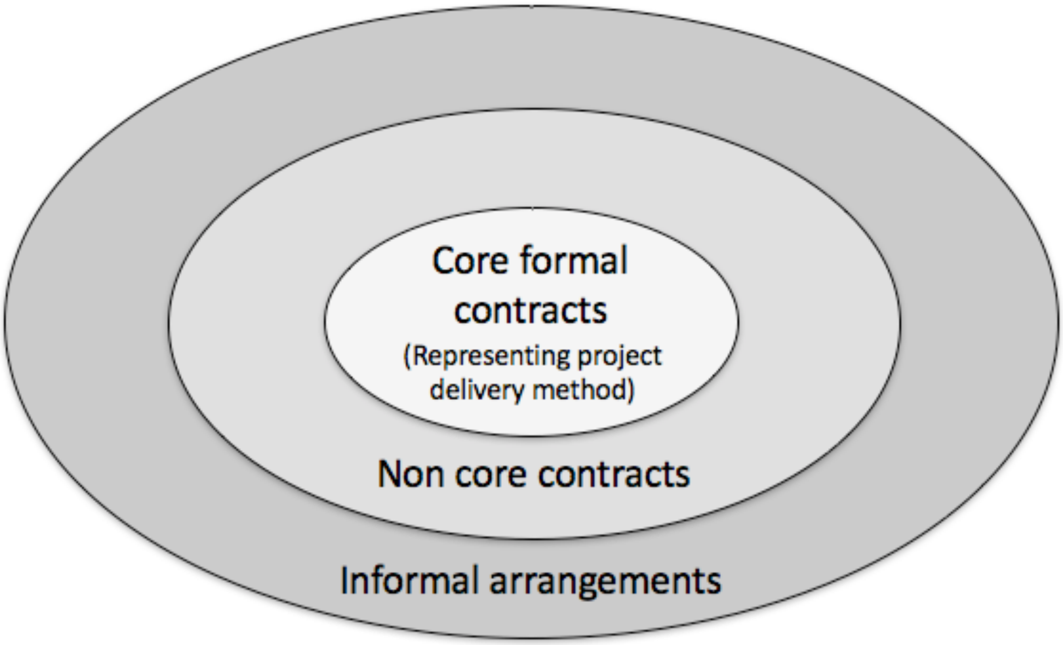

Figure 51: Visualising contracts and informal arrangements within TMFC

The success of renovation projects *i.e.,* achieving the values within the time period, selected by the project principal (*e.g.,* energy savings, financial return, GHG emissions avoided) requires careful configuration of (key) actors. A key element is the alignment of the value propositions offered by different entities to the overarching project objectives. This alignment can be achieved through specific contractual provisions (penalty-based obligations, performance-based payments, *etc*.). At the same time care must be taken to ensure the key actors are suitably rewarded for their contribution, otherwise they may not be suitably motivated to deliver expected contributions *i.e.* they need to be satisficed. The following sections offers a short overview of incentivising firms.

8.1.3 Incentivising firms

Baker (1992, p. 598) notes that 'choosing which quantity or quantities to use in an incentive contract is a central problem in agency theory'. Incentives will only be effective to the extent that the selected performance measures reflects the desired objectives (Dunphy & O'Connor, 2015). In this regard, Baker (1992) posits that objectives are not always clear (giving examples of public bodies and non-profits) and even when they are clear they do not always translate into a contractible performance measure. This reemphasises the importance of not only identifying but weighting the objectives of a renovation project and tailoring contract incentives accordingly.

Setting contract incentives can be relatively straightforward for single bilateral contracts, although care must be taken to do so in a way that cannot be 'gamed', leading to unintentional consequences (Dunphy & O'Connor, 2015). There is however far greater complexity in setting incentives for an undertaking such as a building energy renovation, where there are, for example: (i) multiple bilateral and multilateral contracts; (ii) a mix of sequential and parallel activities; (iii) multiple activities combining to create different results; (iv) temporal lag between actions and outcomes; *etc*.

To incentivise renovation projects it is imperative therefore that clear and measurable overall specific project objectives and their relative importance be established[150] and that a framework of incentives be established throughout the value chain to ensure that key actors are motivated individually and collectively to contribute to the the achievement of the selected objectives. Establishing such an incentivization system requires understanding each (key) actor's contribution towards meeting project objective(s). This can be achieved through methods, which adopt lifecycle approaches such as those discussed in section 3.5.

[150] Such as the three performance measures previously forwarded in this thesis *viz.,* financial return, energy savings, and avoided GHG emissions.

Within the context of the web of actors involved in a TMFC, contracts not only have to incentivise individual actors, but to do so in a manner that boths creates a shared interest in the project outcomes and is considered equitable.

Rose & Manley (2011) observe that financial incentives do not automatically translate into motivation, and that the context in which they are applied is important. They argue that the effectiveness of incentives is increased through equitable contract conditions and within a respectful contracting environment. They conceptualise motivation as arising from four interrelated factors: (i) goal commitment (how attractive and attainable is the goal); (ii) distributive justice (how reward-to-risk ratio of different actors compare); (iii) procedural justice (how fair are incentives procedures); and (iv) interactional justice (how much trust it there between the project principal and actors) (Rose & Manley, 2011).

Trust between the key actors and the project principal should almost be a given within any project, especially one as potentially complex as a renovation project. However, this is not always the case within construction, Chinowsky *et al.,* (2008, p. 807) for example, observe "*the instability of construction project teams, where new teams are configured on a regular basis, often hinders the development of trust relationships*". This should be a key consideration in the initial engagements of a TMFC. Developing procedures for the distribution of incentives that are perceived as just, (*e.g.,* that they are seen as not being open to being gamed) is important to gain acceptance and buy-in to the incentivisation programme and motivate actors towards the project's objectives. Demonstrating such procedural justice will also significantly contribute to developing inter-actor trust.

Ensuring that the goal is both attractive and attainable is a key consideration – setting targets that are unreachable will not motivate anybody not matter what incentives are on offer. In multi-actor scenarios, the attainability of a goal is also related to the effort that other actors are likely to commit, *i.e.,* how motivated will they be. The perceived fairness of the distribution of the incentives is also an important aspect – actors will be demotivated if there is a peception that rewards are unjust and that their efforts are enriching others. Both of these factors indicate the importance of ensuring that the key actors are satisficied, when configuring a building energy renovation.

8.1.4 Satisficing

Simon (1955, 1956) coined the term 'satisfice'[151], a combination of the words satisfy and suffice, for an alternative decision-making strategy that seeks to find an acceptable choice under a limited set of considered options[152]. Jain *et al.* (2013, p. 41) succinctly contrast seeking a 'good enough' solution (*i.e.,* satisficing) with seeking the 'best' solution (*i.e.,* neoclassical economic maximising). Simon (1979, p. 498) posited that in the absence of full information "*decision makers can satisfice either by finding optimum solutions for a simplified world, or by finding satisfactory solutions for a more realistic world*". Satisficing is actually a common approach to decision-making, whether it is acknowledged for it is or not[153]. Wierzibicki (1984, p. 117) says that while optimisation may be used as a tool in (human) decision-making, he questions its use as a goal – observing "*the decision maker has a tendency towards maximization, but might, for some good reason, lose this tendency after attaining his (adaptively formed) aspiration levels*"[154].

A key feature of satisficing is finding a 'good enough' option *i.e.,* searching through available alternatives until a defined acceptability threshold is met (although as Wierzibicki observes above, in some cases this may be an adaptively formed threshold). This good enough approach is important in ensuring that the many entities involved in a project are appropriately rewarded. If all members of a TMFC took a maximising approach to their rewards from a project, as available rewards are typically finite, they would be competing against each other for compensation. This would result in many actors receiving less than

[151] First introduced on page 16.
[152] In what Simon (1979) considers a form of bounded rationality.
[153] G. Johnson *et al.* (2008, p. 33) outline a number of reasons why it is used in place of maximising, including: cost and time limitations; non-availability of information; unpredictability of the future; changing contexts; psychological limitations of decision-makers, *etc*.
[154] Wierzibicki (1984) refers to this form of decision making as quasi-satisficing, although for the purposes of this discussion, this distinction is not particularly relevant.

their minimum threshold – in other words, they would be demotivated regarding the success project, potentially likely to withdraw and may reconsider involvement in future projects. As outlined earlier in the thesis, addressing this requires multi-actor satisficing – this necessitates devising inter-firm relationships and contract rewards in such a manner that all (key) actors receive at least the minimum sufficient value – in their terms – for their contribution to the project. This involves identifying key stakeholders within the TMFC and discerning their minimum consideration thresholds (both in monetary and non-monetary terms) and configuring the project accordingly. Multi-actor satisficing, such as this, will ensure that all (key) actors are motivated to work towards the successful completion of the project. Coupled with a carefully designed incentivisation programme, this will align the interests of the key actors with that of the project and towards achieving the project's objectives.

8.1.5 Towards a satisficed incentivised configuration

The problem statement at the start of this thesis (page 26) present a key objective of this thesis as 'facilitating the development of business models which deliver sufficient value for all stakeholders *i.e.,* yielding sufficient financial return (and other values) for project promoters (thereby addressing market demand) while also providing the various contributing businesses adequate value in return for their contribution (addressing market capacity).' Using the knowledge developed in this thesis and building on the discussions in sections 8.1.1 to 8.1.4, this section explores how the business model concept and associated tools can be used to devise satisficed, incentivised configurations for building renovation projects.

An elaboration of the business model structure from page 132 (with the focal value class for the organisation being financial value expressed in terms of profit) is shown in Figure 52, with the components described below (Dunphy & Morrissey, 2015, p. 17):

1. Value Proposition: bundle of products and services that are of value to the customer;

2. Target Customer: customers to which a company wants to offer value proposition;
3. Distribution Channel: means of getting in touch with the customer;
4. Customer Relationship: kind of link a company establishes with customers;
5. Value Configuration: arrangement of activities and resources that are necessary to deliver project successfully and thereby create value for stakeholders;
6. Capability: ability to execute a repeatable pattern of actions, necessary to create value;
7. Partnership: Voluntarily agreement between the firm and another to create value;
8. Cost: Representation in money of all the means employed in the business model;
9. Revenue Model: how money is made through variety of revenue flows.

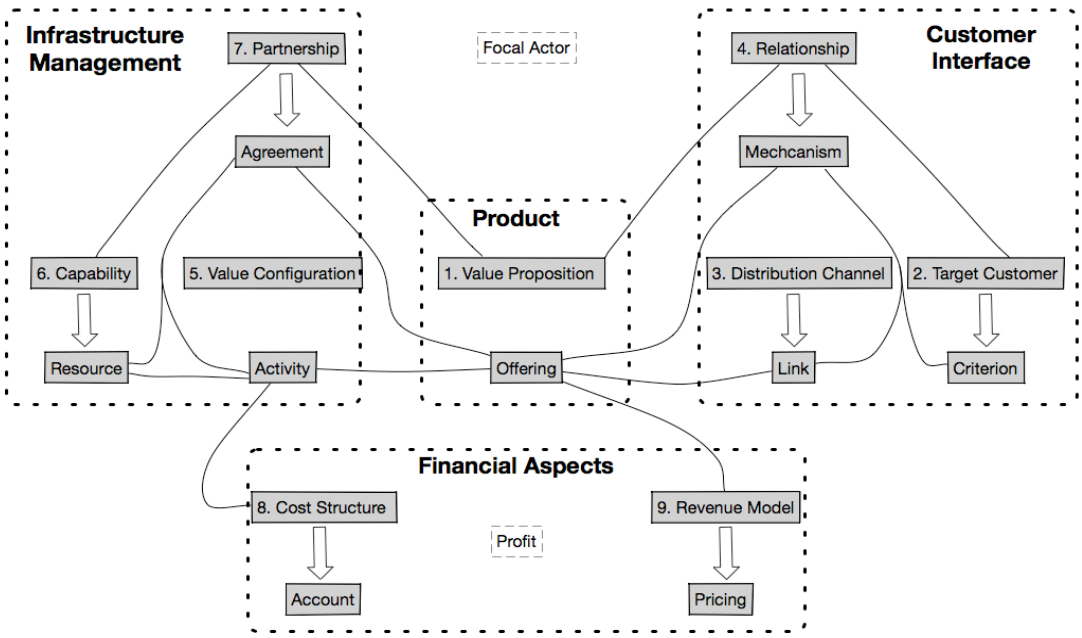

Figure 52: Generic business model structure (adapted from Dunphy & Morrissey, 2015, p. 17)

Figure 53 below illustrates an adaptation of the business model ontology structure for an alternative value, in this case GHG emissions avoidance – in this scenario the focal value class for the organisation is greenhouse gas expressed in terms of GHG emissions avoided (reduction in net GHG emissions within a given time period). In this adaptation, the cost structure and revenue model (#8 & #9 in Figure 52) are replaced by analogous GHG 'expenditure' and 'savings' accounts.

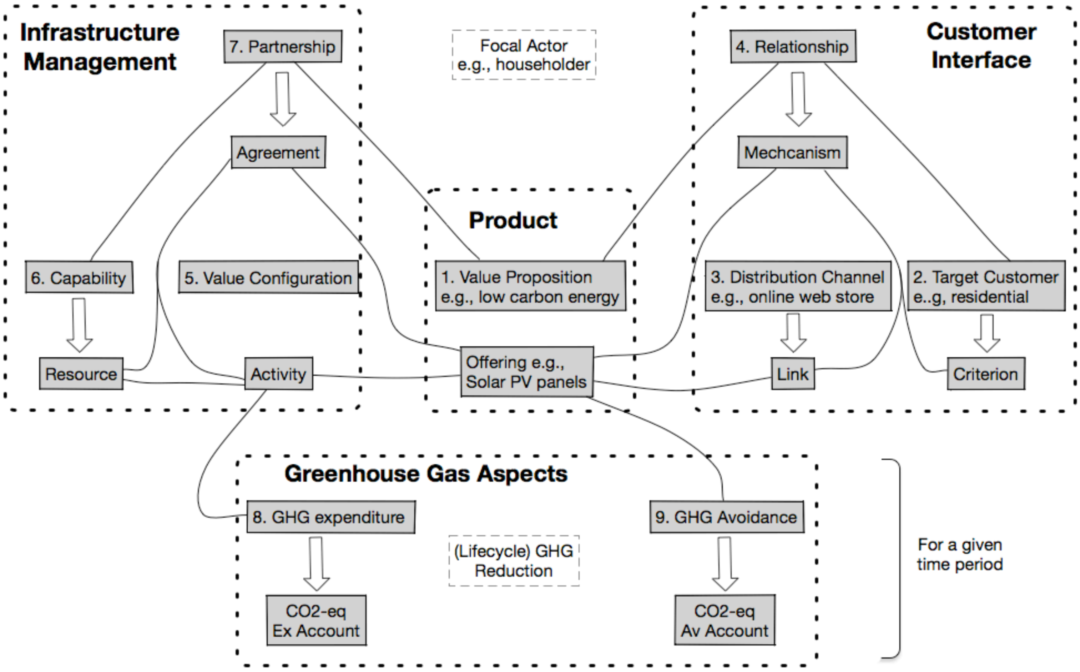

Figure 53: Business model structure adapted for GHG emissions avoidance *(adapted from Dunphy & Morrissey, 2015, p. 18)*

A similar model can be constructed for energy – where the focal value is energy expressed for example in terms of kWh of energy 'saved' as shown in Figure 54 below. The idea is not to attempt to convert the metrics to a common unit (monetary value is often forwarded in this regard). Rather, these are intended as parallel accounting structures using different units of measurement. Project principals decide the weighting to be applied to each metric. Notably, the conventional business model components are silent with respect to temporal issues and while this may be understandable (to a degree) for the traditional business model representation[155, 156], it is not so easy to ignore for energy and GHG emissions as discussed in Section 3.4 on page 78. For that reason, temporal boundaries must be defined at a preliminary scoping stage.

[155] One must assume that the 'Cost Structure' (#8 in Figure 52) reflects and incorporates costs of upstream actors in setting the price paid by the customer.
[156] Such discussion of costs raises the question of representing external societal & environmental costs – consideration of externalities is an interesting issue and while it is outside of the scope of this thesis, such holistic costs could be represented in an adapted business model structure.

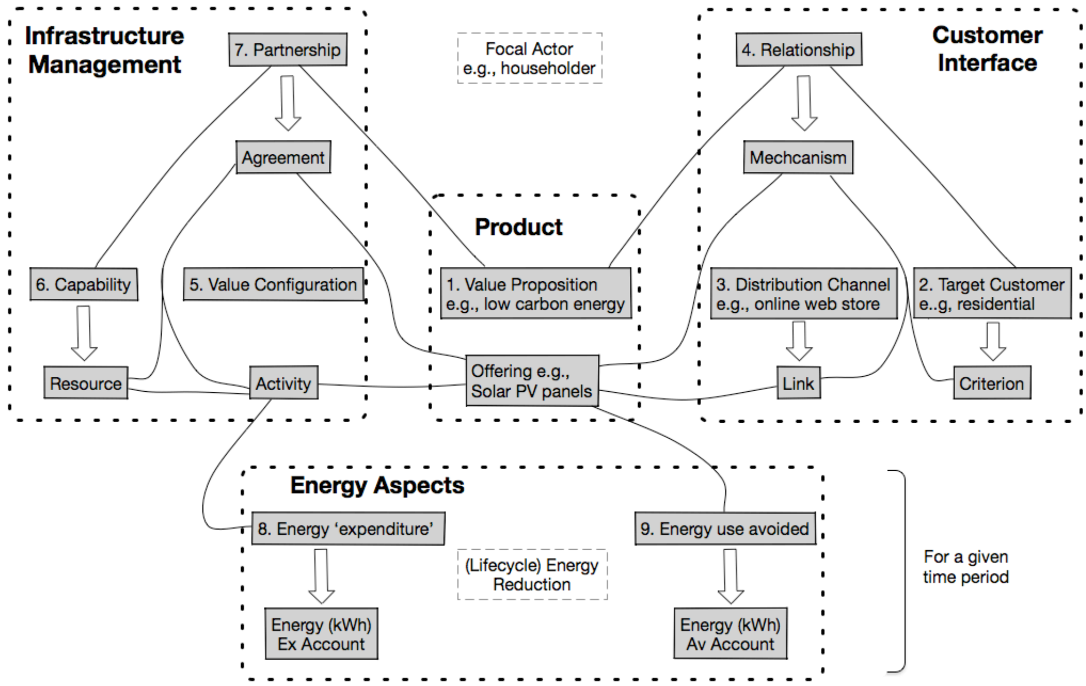

Figure 54: Business model structure adapted for Energy reduction

The use of such additional values is not intended to supplant financial return but rather it is planned that it would be considered in parallel to it, in an expanded multi-perspective business model ontology encompassing a number of values in addition to the tradition profit centric model. For most firms (but not necessarily all, *e.g.,* social enterprises, which are increasing active in housing) profit will be the principal value on which business decisions are made. However, different firms depending on their own circumstances may chose different values to consider and will in fact attach different weightings to such values.

The business model structures presented in Figures 52-54 above can be used as the basis to create value-specific schemata for projects – as mentioned previously different weightings will be attached to each value depending on the wishes of the project principal and the nature of the project. The schemata will detail the negative and positive accounts for each value *e.g.,* in the case of our values of interest: expenditure and revenue; GHG emissions and GHG emissions avoided; energy consumed and energy savings. This process can be used to generate and evaluate alternative configurations, which can directly feed into a decision-making process. Gathering and analysing the data required for these accounts is a heuristic process, and the resultant learning experience may help to formulate alternatives, as much as evaluating them. It will provide an in-depth understanding of the role of actors and can be used to iteratively structure, organise and incentivise the TMFC as mentioned on page 252[157]. The focus on non-monetary values, perhaps not ordinarily considered to such an extent, will result in a greater awareness of the issues involved, as well as on how the individual TMFC firms can improve their contribution to the value class (Dunphy & O'Connor, 2015).

This multi-actor, multi-perspective, multi-value approach outlined above is inherently complex and does not lend itself to simple determinations, this is particularly so in the case of building renovations for example, where the values are likely to be considered over long periods involving some degree of life cycle evaluation. One approach to overcome this complexity is to develop a framework enabling approach as suggested by Dunphy and O'Connor (2015) for the different measures of performance. With such an approach, performance incentives can be applied on a decentralised basis, with the TMFC divided into groups of activities (that could be based on sub-divisions of the hubs of activity forwarded in this thesis) for this purpose. This would allow the organisations involved with the activities within the boundaries of these sub-divisions to operate quasi-autonomously for one or more value classes, with globally set targets but with freedom to achieve these in whatever way best suits locally.

Following this approach, an assessment is carried out for each value class globally, this involve the preparation of inventories (as discussed in section 3.5 on page 104) for different parts of the value chain. This will be done initially as a scoping exercise to identify hot spots[158], which can be subjected to more in-depth review subsequently. The identification of these hotspots (which will not necessarily be the same for different value classes) enables the project principal to focus particular efforts for different value classes in those

[157] *i.e.,* it will contribute to an understanding of key actors' contributions towards meeting objectives
[158] The so-called hotspot approach is common to life cycle assessments and increasingly to be found in energy analyses.

activities where it will likely generate most results.

Thus, it can be seen that translating the business model concept from a single company to project based organisations, such as TFMCs associated with building renovations[159], adds complexity requiring a level of alignment of interests and objectives amongst the component entities (at least for the duration of the project). Satisficing can therefore be seen an important approach strategy for configuring the value propositions of multiple stakeholders for prioritised objectives.

8.2 Revising the research questions

As outlined in Section 1.3, this thesis aimed to address a number of questions, namely:

- Who are the various stakeholders involved in delivering energy renovation projects?
- What functions do stakeholders play in building energy renovation projects and how do they interact with one another?
- What financial and non-financial 'value(s)' do the stakeholders seek from their involvement in building energy renovation projects?
- How can these project values be better understood, so as to contribute to increasing building energy renovation activity?

These questions were addressed through a combination of documentary research and face-to-face interviews with stakeholders across the building energy renovation value chain (as described in Chapter 2). The various stakeholders involved in delivering energy renovation projects were identified and characterised (see Chapters 3 & 5). The various activities in which they were involved were disaggregated and presented as the *hubs of activities* model (see Chapter 5). Adopting this model as a framing mechanism and using the information

[159] Due to their transient nature, mix of formal and informal arrangements etc. TMFCs involved in building renovation may actually add more complexity than others PBOs - For a fuller discussion of the nature of TFMCs see page 24

gathered from the interviewees, important actors, key relationships, influences and outcomes were identified for each of the six stages and illustrative power-interest matrices of relevant stakeholders developed (see Chapter 6). In Chapter 3, three key desired performance metrics for renovation projects were discussed in detail, and methods for creating life cycle inventories for each of the three value classes examined (financial return, reduced energy consumption and avoided GHG emissions). The concept of value, and related ideas such as value chains, business models etc. were explored in Chapter 4, with key findings arising the interviews with members of renovation value chains presented in Chapter 7 (and to a lesser extent in Chapter 6). Finally, in the previous section 8.1, the knowledge developed in earlier chapters, on building renovation value chains, was used to forward a business model approach as a means of satisficing building energy renovation activities, such that it promoted attainment of project objectives, but also that it contributing to maintaining market capacity (by ensuring all key actors are satisficed), the combined effect of both of these would contribute to increasing building energy renovation activity.

8.3 Significance and implications of the research

The research presented in this thesis is a novel trans-disciplinary study, using and combining approaches from a number of academic disciplines including engineering, sociology, and business. Detailed in Chapter 2, the methodology applied in this research, and the methodological explorations underpinning it are themselves useful contributions and can be adopted to other studies both within the construction domain and more widely. The methodology has been tried and tested and proven to be successful in its implementation. As described earlier in this thesis, the methodology developed in this thesis was used by the author in the successful completion of a FP7 project UMBRELLA. Elements of this methodology was also subsequently used by the author and collaborators in a number of subsequent research projects. These include projects: in the construction domain (NewTREND an H2020 project developing an integration renovation design methodology); within the wider energy space (ENTRUST H2020 project exploring the human dimension of the energy system, and Imagining 2050, an EPA project co-producing pathways for a low carbon future) and engineering, (RE-WIND a Science Foundation Ireland-National Science Foundation project focused on the reuse and recycling of decommissioned composite material wind turbine blades).

This thesis presents a useful clarification on the application and worth of the differing perspectives on life cycle as regards buildings. The disaggregation of life cycle energy and greenhouse gas emissions, and the perspectives this enables, can be used for a more comprehensive consideration of the life cycle performance of building energy renovations. This information can then be used (in conjunction with the hubs of activity model mentioned below) to characterise performance risks and contribution to the renovation selection.

This thesis provides a novel application of value concepts to the study of renovation projects. The Hubs of Activity model presented in Chapter 4 represents an important contribution of this thesis, providing a conceptual model for the life cycle consideration of the multiplicity of activities associated with construction projects. As mentioned earlier the systematic description of building energy renovation activities facilitated by the model enables full characterisation of renovation activities across an extended time-horizon which in turn allows for more in-depth consideration of value generation, capture and distribution, directly increasing the knowledge exchange capacity of stakeholders. This model is subsequently being used within the NewTREND H2020 project as a means of value chain mapping and to devise means of greater occupant involvement in renovation process.

8.4 Reflections and limitation

As with any research undertaking, there are a number of limitations to the research approach applied in this study. The in-depth interview was a key data collection method used in the research. By the nature of volunteer interviews, the interviewees were somewhat self-selecting. Although in many cases it took a great deal of effort to get some respondents to agree to participate, the very fact that they agreed to be interviewed differentiates those prospective respondents that refused to take part. Moreover, a substantial number of interviewees were non-native English speakers and while their standard of English was generally impeccable, it is likely that their message could have been simplified, and perhaps nuances lost in the conversion of their thoughts from their native tongue to spoken English.

8.5 Areas for further research

There are a number of potential research avenues that could be developed from this study.

This thesis has not addressed the idea of competing values (as opposed to actors competing for value), or of stakeholder value propositions dependent on actively costing other stakeholders their value. Satisficing stakeholders that seek competing values offers an interesting challenge for future research.

Nor does the research presented in the thesis address the incorporation of externalities (*i.e.* environmental and societal costs that will be borne by the project stakeholders) into the model, except in a very limited fashion through project specific objectives. Incorporating external costs into the model presents rich potential for future work.

The extension of the model to the district or community level (attempted to a limited extent in the subsequent NewTREND H2020 project) greatly increases the number and variety of stakeholders and introduces completely new value considerations. This is an interesting proposition and delivering it in a useable form will be challenging.

Another area that offers potential is the use of the methodology in non-building related domains, it would seem to lend itself to use in a number of areas involving project based organisations. This is something that is planned in the SFI/NSF funded RE-WIND project due to commence in the first quarter of 2018.

8.6 Concluding statement

Capturing the potential energy savings associated with existing building stock requires the application of a deep understanding of how and where values are created within building renovation activities. However, as discussed throughout this project and especially in Chapter 4, the definition of value differs according to stakeholders' role in the renovation process but also the points of view of specific stakeholders[160]. Increasing the amount of renovation activity requires a combination of improving market demand (*e.g.,* by convincing building owners of the preferred value proposition) and ensuring that the market capacity is increased or at least maintained (*e.g.,* by ensuring that all those identified as key actors in the renovation hubs of activity extract sufficient value from their involvement, in whatever terms they define it).

Value capture and distribution within a particular renovation inevitably raises competing interests. Value analysis approaches which seek to understand the positions of all key actors can facilitate satisficed solutions including those with multi-dimensional performance perspectives as discussed in this thesis. Using this knowledge about the actors' value priorities, the conflicting demands can be resolved for a satisficed solution – including (but not limited to) using techniques derived from constraint satisfaction[161]. Such approaches are flexible enough to provide for multi-criteria priorities and outcomes.

[160] Corresponding stakeholders in different renovations may prioritise different value propositions depending on their requirements *e.g.,* some owners place higher value on lower operating costs, return on investment and increased property rental or sales values, while others may have greater preferences for thermal comfort, employee productivity or architectural aesthetics, *etc*.
[161] For example combinatorial optimisation through the use of mathematical constraint programming *e.g.*, multiple decision diagrams as used in Dunphy *et al.* (2012),

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Appendices

Appendix 1 – Typology of Life cycle study standards and guidance documents

The documents below are categorised from the perspective of scope *i.e.*, what is assessed; and of focus *i.e.*, the intended application of the assessment.

<table>
<tr><th>Scope</th><th>Standard</th><th>Focus</th></tr>
<tr><td>Life cycle cost</td><td>EN 16627:2015 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods</td><td>Buildings specific</td></tr>
<tr><td rowspan="3">Life cycle assessment</td><td>ILCD Handbook General Guide for Life Cycle Assessment</td><td rowspan="2">General LCA application</td></tr>
<tr><td>ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework
ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines</td></tr>
<tr><td>EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method</td><td rowspan="3">Buildings specific</td></tr>
<tr><td rowspan="7">Greenhouse gas emissions</td><td>EN 15643-2:2011 Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance</td></tr>
<tr><td>ISO 16745: 2015 Environmental performance of buildings - Carbon metric of a building - use stage performance</td></tr>
<tr><td>ISO/TS 14067:2013 Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication</td><td rowspan="3">Product carbon footprint</td></tr>
<tr><td>PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services</td></tr>
<tr><td>GHG Protocol Product Life Cycle Accounting and Reporting Standard</td></tr>
<tr><td>The GHG Protocol for Project Accounting</td><td rowspan="2">GHG reduction projects</td></tr>
<tr><td>ISO 14064-2:2006 Specification with Guidance at the Project Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals</td></tr>
</table>

Appendix 2 – Interview Schedule Examples

Interview Schedule – Owners

A. Background information

A1 What is your role with respect to the building and/or in the organisation (if one exists)?

notes: statement of their position, but also their views on role and responsibility

Do they have a decision-making responsibility? How long what they been involved?

A2 In your opinion, what is the mission of the organisation?

prompts: what is the purpose? motivation? interests?

notes: how does the informant see its mission? what it can be? what it should be? which services do they offer? which relation do they have with the end-users? what can we do to implement direct communication with the end-users?

A3 How are decisions made within the organisation?

notes: Internal decision-making processes; day-to-day; strategic; use of software and other tools? what time-horizons are typically applied in decision-making? time-scales for energy efficiency payback?

A4 Where does the organisation see itself in relations to the wider community?

notes: links to outside bodies; integrated / separate; education / training / role model roles; commercial links

A5 In the context of such project, what do understand as value?

Follow on

A5a Are you familiar with the value-chain concept?

A5b How do you think the value-chain within the building market evolve?

B. The Project

B1 Can you provide a short description of the property?

B2 Can you describe the energy efficiency project(s) being undertaken?

B3 What are the project's objectives?

Follow on

B3a Where is the 'value proposal' for your organisation?

B3b Are there 'added values' for your organisation from participation in this project?

B4 What is the project timescale?

Follow on

B4a What stage is the project at now?

B4b Is there a dedicated project manager?

B4c Is there a communication strategy?

B5 How are future costs and benefits considered in your company's business models?

Follow on

B5a Is future risk considered as part of this business model?

B5b Have you considered any alternative business models?

B6 What is your company's role in the current project?

Follow on

B6a How does this role work in the context of other stakeholder input?

B7 To what extent is your organisation dependent on other stakeholders to successfully deliver on your responsibilities?

B8 How do you evaluate the gap between your objectives and the available solutions (technical or otherwise)?

B9 Strategically, what is the benefit to your organisation from participating in this project?

notes: Elaboration of most important aspects of the project; weighting and prioritisation of project elements from organisational perspective

B10 How do you describe the external conditions in which the project is embedded?

Follow on

B10a Do you know how your company fits into the EEB value chain?

B10b What do you see as your particular value contribution?

B11 Have you already experienced energy management problems?

Follow on

B11a Are there any insights/lessons from previous or similar projects, which you feel are relevant to this particular project?

B11b Were these previous projects based on a comparable business model?

B12 Which kind of support /partnerships are ideal or work best for your organisation / your particular business model?

B13 Does the project consider its objectives on a lifecycle perspective?

B14 What technology / solutions are being used in the project?

Follow on

B14a From where are they being sourced?

B14b What criteria were applied to arrive at the final decision on these solutions?

notes: intended to capture initial details of technology supply chain; details of decision-making criteria, LCC, NPV, carbon footprint; In-house or Consultancy expertise? Did you encounter any split incentive problems in the selection of the final technology / solution?

B15 Would you have appreciated to have a tool or software that gives you technical and financial information about the potential results of the project?

C. Sustainability

C1 What do you understand by the term sustainability?

Prompts: sustainable development

C2 Is sustainability an issue in public discourse?

Follow on

C2a Are sustainability issues taken seriously by public bodies?

C3 How does sustainability mean (to you) at the building level?

C4 What do you understand from the concept of lifecycle perspective?

Follow on

C4a What are the benefits of a 'lifecycle perspective' from your organisation's point of view?

C5 Does the sustainability paradigm and a lifecycle perspective present any specific risks, threats or opportunities for your organisation?

C6 How does your organisation obtain information on sustainability?

Note: types of hardware and software used, level of research / access to research, Internet use, internal communication

C7 What activities are you involved with in terms of sustainability?

D. Finance

D1 What is the project budget? (what are the planned breakdown of costs?)

notes: respondent allowed to detail as much (or as little) detail as they are willing

D2 How have you determined financial feasibility of the project

Follow on

D2a How have you calculated this figure?

notes: calculations such as ROI? Simple payback? Discounting? etc.

D3 How is the project being funded?

Notes: conventional funding – from whom? green loans – from whom? public schemes – which ones? tax incentives?

D4 Have you received any grant aid or support for this project?

Follow on

D4a If so, was this a decisive factor in undertaking the project?

D5 Was obtaining funding difficult?

Prompts: please elaborate …

D6 Have you received any non-financial support for this project?

Follow on

D6a If so, was this a decisive factor in undertaking the project?

D7 Do you feel there is sufficient support for these types of projects from: policy makers? From b) financiers? Other?

Notes: Suggestions how better support could be provided to project owner

E. Stakeholders

E1 Other than the Organisation – who else is involved in the project

E2 Could you describe your relationships with these stakeholders?

E3 How was the project initiated?

Follow on

E3a How was it designed?

E4 Who is leading / managing the project?

E5 Can you describe the project team implementing the project?

E6 How would you describe the levels of communication with other project stakeholders?

notes: levels of interaction between project stakeholders

E7 Will the project outcomes be shared with a wider group of shareholders?

notes: e.g. through media releases, website articles etc.

E8 Are there neighbours in the vicinity of the project?

Notes: open question to allow respondent to provide details of neighbours; domestic, schools, hospitals, industry, etc.

Follow on

E8a Were neighbours consulted prior to initiation of the project?

E9 Can you describe the local environment in which the project is based?

notes: open question to allow respondent describe environmental context, neighbouring recreational facilities etc.

E10 What interactions does the project have with public bodies?

Prompts: planning authorities / building control; energy agencies; other – give details

E11 Is the project of interest to any non-governmental organisations?

Notes: positive or negative interest

F. Owner specific queries

F1 Could you explain this project in the context of the company's wider operations?

F2 In terms of the scale of company operations, what is the scope to expand the learnings from this project?

F3 How many other buildings / locations could potentially be retrofitted in a similar approach?

F4 How do you envisage that this project will add value to your organisation's activities?

Notes: open question to allow the interviewee to self-define value, before more specific questions direct to prescribed definitions

F5 What is the business model for this retrofit project, or for other retrofit projects, which the company is involved in?

Notes: payback periods; enhanced value of the asset; insurance against future energy prices; activity as part of greening the supply chain

F6 What are the success criteria, which you will apply as owners?

notes: reduced costs; emissions reductions; reputation

F7 Have these success criteria been discussed with the contractor / project manager?

F8 How are the success criteria measured?

F9 Could you describe the working relationship between you and the design team and you and the main contractor?

notes: Identify relationship in context of hubs of activity model

F10 Did you get a sense of the efficiency of other working relationships during the course of the project?

F11 Was there any stage of the project, which you felt suffered from a deficiency of information or lack of technical know-how or support?

F12 Regarding the current project, could you describe the waste management practices and end-of life approach for the material arising's?

F13 How did these approaches arise?

F13a Did particular stakeholders influence the final approach?

F13b Was the approach driven by regulation?

F14 For the materials installed in this project (insulation; glazing *etc.*) is there a replacement and materials recovery plan?

F14a What time horizon do you expect these materials to last?

F15 Is there an end-of-life vision for the building as a whole?

F16 Is there a materials recovery plan?

F16a Who do you see as being responsible for these issues?

F16b Who are the important stakeholders in materials management and end-of-life activities?

G. Closing

G1 - Is there anything else you would like to add?

G2 - Could you recommend two additional stakeholders who you feel it might be useful to speak to for this study?

notes: snowball approach

G3 - Thanks for help & if there are further questions / clarifications needed, do you mind if I get in touch with you again?

Interview Schedule – Construction Contractors

A. Background information

A1 Can you tell me about your company?

notes: What it does? how big is it? how long was it established? etc. *Does it specialise in Building energy efficiency works?*

A2 What is your role in the organisation

notes: A statement of their position, but also their views on role and responsibility; Do they have a decision-making responsibility? How long what they been involved? Hierarchy and Level of Authority: Who do they report to / who reports to them?

A3 What is your background in this type of work

prompts: Why notes: Education, training, experience, professional accreditation etc.

A4 What is the mission of your organisation?

prompts: what's your opinion?

notes: How does this person see its mission? What do they think it should be?

A5 How are decisions made?

prompts: within your organisation? within (specific) project?

notes: Internal decision making processes; Day-to-day – how is work carried out? On permanent teams working independently, project teams, collaboration with outside partners? Strategic; Use of software and other tools?

A6 Where does your organisation see itself in relations to the wider community?

Follow on

A6a Who are your key partners in this (specified example) project?

A7 How would you view your organisation in the industry generally?

A8 Do you think your company to approach business is future-proofed?

prompts: how?

notes: future risks, costs and benefits considered in business models?

B. The Project

B1 Can you talk about a building energy renovation project on which your company is currently working?

prompts: or was recently undertaken by your organisation? Are there any issues?

notes: Open question to allow respondent to explain their view of the project; building description; type and scale of project; proposed solutions; aims and objectives; etc.

B2 How did your company get involved in that project?

B3 What was your company's role in the project? (Budget?)

B4 How does this project fit into the organisation's mission?

Follow on

B4a and into wider activities and plans?

prompts: Which do you think are most cost-effective?

notes: any particular significance for organisation? application of outcomes; similar projects, *etc.*

B5 from a strategic point of view; do you see benefit to your company from participating in this project?

notes: elaboration of most important aspects of the project; weighting and prioritisation of project elements from organisational perspective

B6 Other than your own company – who else is involved in the project?

Follow on

B6a Please describe your relationship with these other companies

B6b What was their role? (budgets?)

B7 Would you be prepared to invest with the owner in energy savings measures in return for a share of the savings?

prompts: would you be prepared to pay more (rent) for a more-energy efficient building?

B8 To what extent is your organisation dependent on other organisations to successfully deliver on your responsibilities?

notes: Identification of value networking activities, business ecosystem patterns

B9 What would see as obstacles for the project? Are there any objectives or ideals that had to be dropped due to time constraints, cost, policy, practicality, availability or other reasons?

B10 Is sustainability considered with when establishing objectives?

prompts: or a life cycle perspective? How?

B11 Are there any insights/lessons from previous or similar projects, which you feel are relevant to this particular project?

C. Energy Renovation Projects

C1 What do you understand by the term sustainable development, and how does it apply to you and your company?

C1 What do you understand by the term lifecycle when applied to buildings?

notes: lifecycle thinking, approach, methods, perspective, energy analysis / assessment / costing?

C2 To what extent are concepts such as sustainability and lifecycle approach incorporated into the delivery of the project?

C3 How do you feel sustainability and energy use is being addressed within the construction industry?

C4 What are the advantages and disadvantages of sustainability and lifecycle approach from your organisation's viewpoint?

Follow-on

C4a Do they present any risks or opportunities?

C5 What informs your decision to specify materials and products and technologies in projects?

C6 How do you feel governments and public bodies are addressing sustainability and energy use in the built environment?

C7 What is your view of current government approaches to building energy efficiency?

C8 How do you feel sustainability and energy use is being addressed within the construction industry?

C10 Who do you consider to be the stakeholders of the project?

notes: Open question to allow respondent to provide their opinion

C11 Which are the most influential? Most interested in energy efficiency?

Follow-on

C11a Have you considered external people and groups? Who?

C11b Where does your organisation obtain information on energy efficiency?

D. Marketplace

D1 Can you describe your experience with suppliers and other contractors on this and similar projects?

D2 How enthusiastic are building owners (in general) about energy efficiency projects?

D3 What do you see as the major problems for companies involved in the building energy efficiency marketplace?

D4 Who do you see are your main competitors?

D5 What are the major problems for companies involved in the building energy efficiency marketplace?

D6 What do you see as the major problems for companies involved in the building energy efficiency marketplace?

D7 How would you describe the company's overall building energy efficiency expertise, both broadly and as a result of this project?

D8 Is existing policy sufficient for support building energy efficiency?

Follow-on

D8a What changes would you suggest?

D9 Do you feel there is sufficient support for building energy renovation projects from: (a) financiers? (b) owners? (c) construction partners/supply chain

E. Closing

E1 - Is there anything else you would like to add?

E2 - Could you recommend two additional stakeholders who you feel it might be useful to speak to for this study?

notes: snowball approach

E3 - Thanks for help & if there are further questions / clarifications needed, do you mind if I get in touch with you again?

Interview Schedule - Occupiers

A. The Building

A1 - Can you provide a short description of the property?

notes: apartment, house, offices; Location, age, area m², type of heating/AC, lighting etc.

A2 - Can you provide some information about you / your organisation

notes: domestic - age, gender, family, numbers living in unit, etc.; commercial - company size, activity, age, number of occupants, etc.

A3 - What is your relationship to this building?

prompts: owner-occupier; tenant; end-user; occupier? For how long?]

notes: A statement of their position, but also their views on role and responsibility. do they have a decision-making responsibility? How long have they been involved?

A4 - What time frame do you envisage for this relationship?

notes: length of lease, level of commitment to this building

A5 - What are the defining factors of your relationship with the building?

prompts: Why do you continue to be a tenant/end-user/occupier

notes: motivations, financial, comfort, convenience, location, facilities

A6 - Could you define the level and type of interaction you have with the owner(s)?

notes: If NOT owner-occupied

A7 - How are decisions about building use made?

prompts: use of software and other tools? what time-horizons are typically applied in decision-making? time-scales for energy efficiency payback?

notes: internal decision-making processes, day-to-day, Strategic

A8 - For energy related matters and this building, who would be your first point of contact?

notes: Owner, neighbours, owner, ESCO, contractor?

B. Energy use

B1 - What is your relationship with energy use and energy use management of the building?

prompts: Are there any issues?

B2 - Would you define any energy management problems in the building at present?

B3 - Could you comment on your current levels of expenditure on energy use in the building and your views on this?

B4 - Are you aware of the potential measures you could carry out to decrease the bill?

prompts: Which do you think are most cost-effective?

notes: lighting, insulation, windows, HVA etc.

B5 - What are the main influencing factors on this level of energy expenditure?

notes: comfort expectations? price of energy? efficiency issues?

B6 - Have you ever discussed energy use with the landlord/owner?

B7 - Would you be prepared to invest with the owner in energy savings measures in return for a share of the savings?

prompts: would you be prepared to pay more (rent) for a more-energy efficient building?

C. Energy renovation projects

C1- What are the plans for energy efficiency / energy management initiatives in the building?

Follow on

Can you describe the energy efficiency project(s) being undertaken?

prompts: What are the project energy savings?

notes: open question to allow respondent to explain their view of the project(s)

C2 - Who had the first idea for the Energy Efficiency project?

prompts: Who took the decision to start the project?

Follow-on

C2a - Why did you decide to carry out this energy efficient project?

notes: energy savings, financial savings, increased (sale/rental) value of building? utility / comfort? compliance? avoiding greenhouse gases? other environmental concerns? certification (LEED, BREEAM, HQE…)?

C3 -What are the project's objectives (from your viewpoint)?

prompts: Are there 'added values' for you and from participation in this project? how are the energy savings to be shared?

notes: energy savings, financial savings, increased (sale/rental) value of building? utility / comfort? compliance? avoiding greenhouse gases? other environmental concerns? certification (LEED, BREEAM, HQE…)? etc.

C4 - What is the benefit to you and other tenants/end-users/occupiers from this project?

notes: elaboration of most important aspects of the project; weighting and prioritisation of project elements from organisational perspective

C5 - Are you aware of funding initiatives for EEB in your country? And at EU level?

notes: local government / national government? EU institutions? other public bodies – which? conventional funding – from whom? green loans – from whom? public schemes – which ones? tax incentives; pay-as-you-save

Follow-on

C5a - How is the project being funded?

C5b What is the project timescale?

D. Stakeholders

D1 - Who else is involved in the project, and what is your relationship with them?

notes: open question to allow respondent to provide their understanding of the other stakeholders involved

D2 - Can you describe the project team implementing the project?

Notes: architects, engineers, craft workers, other specialists, etc.

Follow-on

D2a - what are the services they offer and what are the prices?

D3 - Are there neighbours in the vicinity of the project?

notes: Open question to allow respondent to provide details of neighbours

prompts: domestic, schools, hospitals, industry, etc.

Follow-on

D3a - Were neighbours consulted prior to initiation of the project?

D3b - Are you aware of a smart city – local objective in your town?

D4 - Can you describe the local environment in which the project is based?

notes: Open question to allow respondent describe environmental context, neighbouring recreational facilities etc.

D5 - What interactions does the project have with public bodies?

notes: Planning authorities, building control, energy agencies, others?

D6 - Is the project of interest to any non-governmental organisations?

notes: Positive or negative interest

E. Sustainable Development and Lifecycle Energy

E1 - What do you understand by the term sustainable development

notes: respondent to explain their understandings; why SD is or is not important? Does this concept have a role in the workings of the organisation? In what way is it important (to you): How is this importance shown?

E2 - Is Sustainable Development an issue in public discourse?

Follow on

E3a - Are Sustainable development issues taken seriously by public bodies?

notes: local government, national government; / EU institutions

other public bodies – ask for examples

E3b - Is it integrated in decision making?

notes: ask for examples

E3 - How does sustainable development meant to you at the building level?

Notes: Allow respondent to elaborate

E4 - What do you understand from the concept of lifecycle perspective?

notes: Allow respondent to elaborate

Follow on

E4b - What are the benefits of a lifecycle perspective from your point of view?

E5 - Does the Sustainable Development paradigm and a lifecycle perspective present any specific risks, threats or opportunities for you?

E6 - How do you obtain information on sustainability?

prompts: hardware and software used; level of research / access to research; internet use; internal communication

E7 - What incentives would encourage you to implement building energy efficiency measures?

F. Closing

F1 - Is there anything else you'd like to add?

F2 - Could you recommend two additional stakeholders who you feel it might be useful to speak to for this study?

notes: snowball approach

F3 - Thanks for help, and if there are further questions / clarifications needed, do you mind if I get in touch with you again?

Appendix 3 – List of interviewees

Legend:
ND Interviews conducted by author
UCC Interviews conducted by UCC researcher directed by author
PART Interviews conducted by local partners instructed by, and work with support of author

Table 18: Stakeholder interviewees, Spain

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Mateo	Designer	Business Development	Engineering consultancy	PART
Rogier	Contractor	Owner	Construction firm	PART
Eva	Manufacturer	Owner	Smart meter manufacturer	PART
Miguel	Owner	Partner	Developer	PART

Table 19: Stakeholder interviewees, United Kingdom

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Ian	Owner, Occupier	Eco-village resident Owner-occupier	*Not applicable*	ND
John	Main contractors	Business owner	Construction firm	ND
Hamish	Owner, Project manager	Principal sustainability officer	Local authority	ND
Olive	Occupier	Eco-village resident	*Not applicable*	UCC
Clive	Project manager	Projects manager	Developer	UCC
Anne	Owner, Occupier, Project manager, Energy provider	Eco-village resident Various roles within intentional community including projects, energy, education *etc.*	Intentional community	ND
Philip	Building control	Principal building standards officer	Local authority	ND
Fred	Project manager, Designer	Energy engineer	Local authority	ND
Alice	Policy maker	Retrofit officer	Local authority	ND

Table 20: Stakeholder interviewees, Germany

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Rupert	Building control	Project coordinator	State agency	ND
Morgane	Training organisation	Member regional centre expertise sustainable construction	Building industrial training body	ND
Kristin	Research and development	Project coordinator	Building exhibition	ND
Jörg	Manufacturer	International product manager	Insulation manufacturer	ND
Hens	Research and development	Project leader	Sectorial research body	ND

Table 21: Stakeholder interviewees, Italy

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Alberto	Manufacturer	CEO	Appliance manufacturer	PART
Roberto	Designer	Employee	Architect practice	PART
Valeria	Designer	Owner	Architect practice	PART
Maria	Finance	International affairs	Bank	PART
Giulia	Energy provider	Executive	Energy utility	PART
Umberto	Energy provider	Company manager	Energy utility	PART
Evita	Energy provider, Project manager	Company manager	Energy utility	PART

Table 22: Stakeholder interviewees, Sweden

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Brian	Owner, Contractors	Technical director	Construction company / developers	PART
Valter	Designer	Architect	Architect practice	PART
Viktor	Municipality	Environmental coordinator	Municipality	PART
Elsa	Research and development	Project manager	Local energy agency	PART
Sven	Research and Development	Programme secretary	Buildings research centre	PART

Table 23: Stakeholder interviewees, Denmark

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Anders	Designer	Retrofit designer	Large management consultancy firm	UCC
Paul	Research and Development	Project manager	Not-for-profit non-governmental organisation	UCC
Jo	Policy maker	Manager, municipality	Municipality	UCC
Bjørn	Research and development	Project leader	R&D organisation	UCC
Michael	Project Manager	Energy consultant	Large energy consultancy firm	UCC
Thomas	Research and development	Project manager	Industry association	UCC
Jans	Owner	Lawyer (on behalf of private owner)	*Not applicable*	UCC
Carl	Designer	Architect	SME architect practice	UCC
Adam	Owner	Owner representative / project manager	Philanthropic firm & building owners	UCC

Table 24: Stakeholder interviewees, Ireland

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Áine	Designer	Architect	Architecture company	UCC
Seamus	Designer	Architect	Architecture company	UCC
Clodagh	Designer	Architect	Architecture company	UCC
Séan	Waste exchange	Company representative	Resource exchange network	UCC
Peadar	Main contractor	Industry representative	Industry group	UCC
James	Owner	Project researcher	Educational institution	UCC
Ruarí	Building manager	Energy/retrofit manager	Educational institution	UCC
Roisin	Owner Project manager	Retrofit manager	Care home	UCC
Eoin	Project manager	Project engineer	Public sector owner	UCC
Ciara	Utilities Policy makers	Policy advisor	Utilities company	UCC
Aodh	Finance Policy makers	Policy advisor	Public sector policy / finance	ND

Table 25: Stakeholder interviewees, France

Key	*Stakeholder type*	*Interviewee*	*Organisation*	*Interviewer*
Léa	Manufacturer	Business owner	Smart meter company	PART
Pierre	Owner	Co-ownership president	Housing co-operative	PART
Marc	ESCO	Services development director	Energy services company	PART
Olivier	Designer	Business owner	Architect practice	PART
Marcel	Owner	Energy efficiency director	Developer	PART
Jean	Finance	Director	Public association	PART
François	Policy maker	Manager, energy efficiency projects	Public body	PART
Bastion	Designer	Owner	Engineering firm	PART

Appendix 4 – Examples of project delivery models[162]

Design-Bid-Build (DBB): considered the traditional approach to project delivery. The project owner contracts with separate entities for the design and construction. An architect or consulting engineer is retained to develop project designs from which bid documents are produced and contractors bid to construct the project.

Design-Build (DB): the design and construction services are contracted from a single organisation (or consortium), the design–build contractor (who may be a contractor, architect, energy service company, *etc*.); this may also be likened to a one-stop-shop approach. This approach results in single point of responsibility and minimises risks for the project owner. While often seen as a novel approach, DB historically referred to as master builder actually predates DBB and has been in existence for many hundreds of years (Ibbs, Kwak, Ng, & Odabasi, 2003).

Design-Build-Finance-Operate (DBFO): the project owner contracts an organisation (or a consortium) to develop and provide an asset fulfilling established requirements. The grantee designs, builds, owns, develops, operates and manages an asset for a set contractual term. Operational costs are recouped and return on investment obtained through a series of unitary payments made by the grantor over the duration of the contract. This arrangement does not involve obtaining an asset; effectively it comprises the procurement of a service within fixed buildings, over a fixed period of time – at the end of the concession period there is no automatic obligation for ownership to be transferred. The grantee retains ownership and so benefits from any residual value of the project. Such project structures are used to minimise funding requirements and debt obligations of the project owner (Bovis, 2010; Renda & Schrefler, 2006). Variants of DBFO schemes include: Build-Own-Operate (BOO); Build-Develop-Operate (BDO); Design-Construct-Manage-

[162] This content of this appendix was first presented as part of a research report, *viz.,* Dunphy & O'Connor (2015)

Finance (DCMF).

Build-Operate-Transfer (BOT): the project owner grants an organisation (or a consortium) the right to finance, build and operate a facility for a stated period of time, during which time it receives payment. Ultimately the facility is transferred back to the grantor at the end of a predetermined period, when it is believed the grantee will have received satisfactory financial return (Quiggan, 1998). Variants include: Build-Own-Operate-Transfer (BOOT); Build-Rent-Operate-Transfer (BROT); Build-Lease-Operate-Transfer (BLOT); Build-Transfer-Operate (BLO); Design-Build-Operate-Transfer (DBOT); Design-Build-Operate-Maintain (DBOM).

Lease-Develop-Operate (LDO): the project owner leases (or in some variants sells) an existing asset to an organisation or a consortium, which renovates, modernises, and/or expands it, and then operates the asset for a set contractual term. Operational costs are recouped and return on investment obtained through a series of unitary payments over the duration of the contract. At the contract completion, ownership reverts to the project owner (whereas when the asset is purchased there is no obligation to transfer ownership at the end of the contract) (Renda & Schrefler, 2006). Variants of leasing-type schemes include: Buy-Build-Operate (BBO); Wrap-Around-Addition (WAA).