Lowering CO_2 emissions: A framework for overcoming institutional pressures and diffusing low carbon strategy throughout the construction supply chain

By

Emily Kathleen Jervis

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Abstract

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Emily K. Jervis

The construction industry is responsible for approximately 50 per cent of global greenhouse gas emissions (Ramesh et al., 2010). With an increase in anthropogenic emissions linked to the rise in global temperatures and climate change, many of the most highly emitting industries have been coerced in to looking for ways to measure their emissions outputs in line with potential emissions legislation (Wang, Chang and Nunn, 2010; Ortiz et al., 2009). The response to the perceived pressure has been an industry movement towards the use of technological measurement systems. In recent times there has been an abundance of life cycle analysis (LCA) technology available, however, thus far none have achieved widespread uptake in the construction industry (Strategic Forum for Construction, 2010). The technological understanding of emissions measurement is apparent yet the industry has failed to implement it. The lack of uptake has led to a perception that the problem faced may not be entrenched in the technology but may be due to behavioural characteristics of the construction industry itself.

The motivation for this research was the sponsoring company's drive to redevelop LCA by understanding the associated behavioural barriers to its development and implementation. The purpose of this research was firstly to analyse the failures of technological life cycle analysis methods, with the prospect of formulating a novel supply chain perspective to LCA, capable of understanding behavioural barriers to sustainable construction. By addressing construction supply chain structures and institutional barriers to the diffusion of innovative strategy, an evaluation of the impact that institutional isomorphic pressure has on the diffusion of low carbon innovation was facilitated. Understanding the construction industry as an institution enables an understanding of how behavioural implications impact the introduction of novel practices.

Due to the quantitative focus of previous research, empirical data was collected using qualitative methods consisting of a focus group and a series of expert interviews with construction industry professionals. The qualitative approach addressed the need for research which moves beyond the generalisation of quantitative findings in prior emissions studies. The results show that the most important factors in the construction industry which impact on the diffusion of low carbon strategy are centred on the supply chain, client power, collaboration, risk and cost. The noted themes were found to link to institutional pressures which inhibit the diffusion of low carbon innovation. The result of the data collection was the development of a networked supply chain model which could theoretically help the industry to transcend institutional pressure barriers though collaborative approaches to LCA.

The key implication of the study is the acknowledgement of the criticality of collaborative approaches in LCA. The resultant networked supply chain model alongside the establishment of key institutional pressure barriers could have a positive effect on the future development of life cycle analysis systems. The hierarchical and linear structure of the current supply chain is not conducive to low carbon construction. The contribution of this research is the furthering of collaborative supply chain knowledge in the development of low carbon construction.

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To my parents -

A very special thank you to my Mum Rowena for being there for me through many difficult times during this process, and finally, my eternal gratitude goes to my wonderful Dad Robert for his constant and unwavering belief in me, endless support and for helping me to achieve my dreams in all of life's endeavours. I dedicate this thesis to him.

List of tables and figures

List of figures **Page**

List of Tables

Acronyms and abbreviations

LCA	Life cycle analysis
CO_2	Carbon Dioxide
TQM	Total quality management
QFD	Quality function deployment
CMM	Capability maturity model
PM^2	Process maturity model
E I-O	Economic input output
EPD	Environmental product declaration
BIM	Building Information Modelling
IFC	Industry foundation classes
SCP	Supply chain position
TBL	Triple bottom line
ROA	Return on Asset
RQ	Research question
N	Normative
M	Mimetic
C	Coercive

Contents

Chapter 3.0

Methodology

Chapter 1.0 – Introduction

1.1 Chapter overview

The first chapter of this thesis introduces the research into overcoming institutional pressures which inhibit the diffusion of low carbon strategy in the construction industry. It provides a research background, addresses how the research will be carried out and outlines current failures in life cycle analysis (LCA) systems. It also presents the motivation for the research, the key problem, purpose and significance of the study, alongside the research design, research questions, structure and scope of the analysis.

1.2 Background: Rising CO_2 emissions in the construction industry

The construction industry is arguably one of the most vibrant, challenging and high risk industries on earth (Vrijhoef and Koleska, 2000). It is worth in excess of £100bn to the UK economy alone, equating to nearly 10% of GDP (Strategic Forum for Construction, 2010). Globally and without exception, the industry is seen as a token of economic status, vital for socio-economic development (Asif et al., 2007). The importance of construction economically is manifest; however an underlying concern within the industry over the last 30 years has been the overwhelming contribution it makes to environmental degradation (Ofori, 2000a). A large contributing factor to the industry's global environmental impact is its high production of carbon dioxide (CO_2) (Minx et al., 2011). Responsible for approximately 50 % of global greenhouse gas emissions (Ramesh et al., 2010), the focus has moved towards the construction industry to lower CO_2 outputs in the wake of the concerning climatic effects of increasing anthropogenic emissions (Wang and Chen, 2013). With the threat of a rise in global temperatures in sight, governments have been forced to recognise the most highly emitting industries, of which construction is one (Wang, Chang and Nunn, 2010; Ortiz et al., 2009). In view of this the industry has made steps towards implementing measurement systems for CO_2 life cycle analysis in line with potential future emissions legislation (Asif at al., 2007, Strategic Forum for Construction, 2010). Lowering the environmental impact of the built environment has become an increasingly popular area of research with scholars using technological and mathematical means for calculation (Atkinson et al., 1996; Adalberth, 1997; Guinée et al., 2010; Buyle et al., 2013).

1.3 Research overview

The research presented in this thesis examines the prospect of using collaborative supply chain networks to overcome institutional barriers and aid the diffusion of low carbon decision making strategies in the construction industry. It aims to understand the technological, scientific and behavioural challenges of CO_2 life cycle analysis. By addressing the key failings in the current low carbon construction process, it seeks to understand how managing life cycle data collaboratively, using a supply chain perspective, could address some of the key issues in the development of low carbon construction.

The phenomenon of how the failings of LCA could be overcome is examined through the use of two theoretical lenses; DiMaggio and Powell's (1983) institutional theory and Rogers (1971) diffusion theory. Institutional theory is used to explain how institutional isomorphic pressures impact on the implementation of low carbon practices, whilst diffusion theory is used to understand how low carbon innovation could spread throughout the industry. Used together the two theories provide insights into how institutional pressures exerted on the construction industry can aid or inhibit the diffusion of low carbon innovation. It is also able to provide understanding of how these institutional pressure barriers may be overcome. Empirical data has been collected using a qualitative approach to garner industry perspectives on key sustainability issues, thus addressing the need for research which moves beyond the generalisation of quantitative findings in emissions studies. The aim is to move towards a holistic supply chain approach which is thought to be missing from current analyses (Koh et al., 2013). Finally the research will present a conceptual analysis of the noted problems by outlining a collaborative and integrative supply chain method to carbon calculation, expanding the focus of LCA beyond the construction site throughout project supply chains.

1.4 The failures of current LCA systems

Life cycle analyses have been in existence since the 1960s in a much simpler form than today but did not appear in the construction sector until the 1980s (Guinée et al., 2010; Buyle et al., 2013; Bekker, 1982). LCA systems have long been an important aspect of the economics of construction in terms of efficiency and best practice however, never before has LCA been as important for sustainability as it is today, particularly with perceived climate change risks and potential future legislative requirements to lower emissions (Ding, 2008; Glass, 2012; Baek et al., 2013; Buyle et al., 2013). Since the conception of LCA there has been an extensive array

of software available for calculating CO_2 emissions in building design and construction. Tools including IMPACT, ELODIE, GaBi, BEES, SimaPro, Life Cycle Explorer and the Athena Impact Estimator, have all been implemented with the aim of measuring emissions (Chevalier et al., 2009; Singh et al., 2011; Pieragostini et al., 2012; Norris and Yost, 2001; Hischier, 2011). These software tools have had limited success, arguably due to lack of client interest, focus on cost, a lack of enforced legislative and regulatory requirement and a saturated product market whereby the implementation of LCA tools is considered high risk. The element of the 'unknown' with CO_2 LCA in a high risk industry which focuses on the use of tested methods, means that implementation of novel LCA technology is not a preferred option for construction companies (Abderisak and Lindahl, 2015; Heijungs et al., 2009; Blayse and Manley, 2004). These factors have led to widespread indecision with regard to emissions analysis and low carbon decision making strategies (Yang and Chen, 2015; Toole, 1998). Despite the lack of uptake of measurement tools, the market saturation of calculation products has continued to occur with new products such as IMPACT and Wood for Good (BRE, 2014; Wood for Good, 2015). More importantly, CO_2 has continued to increase in construction on an annual basis even with an abundance of technology (Strategic Forum for Construction, 2010).

One of the most apparent shortcomings of current LCA technology is its firm-centric focus which disregards supply chain inputs (Koh et al. 2013). It is argued that one reason for this may be the parochial view adopted by construction projects, whereby on-site project management control the emissions calculations and low carbon decision making (Vrijhoef and Koskela, 2000). There is a possibility that that the expansion of the carbon calculation process across the supply chain, rather than concentrating solely on the firm carrying out the assessment, could have significantly positive implications for carbon calculation. A strategy such as this could reap the benefits of collaboration between supply chain actors for calculating CO_2. The subsequent research assesses the potential for collaborative low carbon decision making methods in evaluating direct and indirect emissions which arise due to decision making processes. Despite the perceived benefits of collaborative systems and supply chain integration (Dainty et al., 2001: Orlander, 2007; Bal et al., 2013) a deep understanding of total life cycle emissions through collaborative supply chain approaches is still an elusive area of research, although supply chain management and collaboration have been addressed as research areas in their own right (see Briscoe and Dainty, 2005).

1.5 Research Motivation

The research was funded by the Centre for Global Eco Innovation and Phlorum Ltd: an environmental consultancy SME who sponsored the project. Their aim was to improve previous LCA software developed by the company in order to position it appropriately into current markets. The motivation for this research came from Phlorum's drive for redeveloping LCA; encapsulating not only the scientific aspects of emissions calculation but also addressing the behaviour of construction companies, and how this impacts on low carbon construction. Prior research into LCA technology products by Phlorum led to the development of a mathematical calculation tool which was proving difficult to position in the market; most likely due to the saturation of measurement products. In view of this, the preliminary indication was that a new product or strategy must provide a novel solution to the emissions problem in order for diffusion of that product or strategy to occur (Gatignon and Robertson, 1985; Hill, 1970). In order to assess the potential for low carbon innovations to diffuse, an understanding of the way institutional pressures impact on the diffusion process was also an important area of analysis. An institutional pressure analysis was important due to the traditional and institutionalised nature of the construction industry which often acts as a barrier to change (Orstavik, 2014; Forster et al., 2015).

The review of the extant LCA literature revealed a gap in knowledge regarding behavioural and decision making procedures when implementing low carbon strategies. With the literature outlining a heavily technological focus, this research aims to provide a social understanding of CO_2 life cycle analysis. The concept of a supply chain approach to LCA forms the basis of this Ph.D research. Despite the encouraging developments in LCA technology since its conception, the essence of failure appears to be human centric involving issues such as collaboration and supply chain integration.

1.6 The problem

There are vast amounts of technology currently on the market for CO_2 life cycle analysis (Ding, 2008). The level of technology has saturated the market with products which are struggling to gain momentum in terms of uptake rates within the construction industry. Available technologies have predominantly been designed to provide a mathematical calculation of carbon emissions. The firm focussed aspect of calculation does not account for external carbon outputs and facilitates the retrospective approach to carbon emissions

analysis, disregarding the benefits of collaboration (Koh et al., 2013; Abanda et al., 2013; Poudelet et al., 2012).

Despite the increasing numbers of LCA technologies available, emissions are continuing to increase in the construction industry and demand for calculation remains low (Strategic Forum for Construction, 2010). Low demand for carbon assessment technologies alongside increasing emissions has led scholars to question whether the solution to the emissions problem is in fact behavioural rather than technological. There is currently little understanding of how LCA technologies could be implemented as a standard part of construction practice. A need to address the barriers to low carbon construction and how these barriers can be overcome to diffuse low carbon strategy has emerged in the wake of potential future legislation (Department for Energy and Climate Change, 2008).

1.7 Purpose and significance of study

In view of the LCA literature taking a predominantly mathematical and quantitative approach the method of data collection in this research was carried out using qualitative methods. A previous focus on mathematical calculation in the literature had revealed an underlying knowledge gap in the area of supply chain based behaviours with specific focus on carbon emissions in the construction industry. The acknowledgement of the limited literature on the human behavioural implications of LCA and a need for increased supply chain based research provided the impetus for a focus on qualitative methodology. The core purpose of the study is to understand and present an argument for how low carbon decision making could be facilitated in the construction industry through the implementation of collaborative supply chains. By using DiMaggio and Powell's (1983) institutional theory, the study illustrates that coercive, normative and mimetic pressures act as both enablers and inhibitors for the diffusion of low carbon innovation. Rogers (1971) diffusion theory is used to aid the understanding of how innovations are adopted and diffused throughout the construction industry. Specifically, institutional theory can provide explanation for why institutions remain the same through institutionalised isomorphic pressure. It is not able to explain how these pressures can be overcome to stimulate change and diffuse novel ideas. To ensure that the theoretical gaps were bridged, diffusion theory was used to extend institutional theory to address how isomorphic pressures could be overcome through using diffusion techniques i.e. collaboration. The combined use of theory presented a new theoretical perspective for

addressing and overcoming sustainable construction barriers, whilst simultaneously providing a practical output for carbon calculation based on collaborative supply chain models.

1.8 Research design

The technological focus of previous literature (i.e. Chevalier et al., 2009; Hischier, 2011 Frischknecht and Rebitzer, 2005) had provided weight to the argument for a qualitative and inductive methodology. The qualitative methodology has the sole purpose of moving away from the previous focus on quantitative approaches to emissions analysis research. Qualitative methods provide potential for acquiring rich data sets to enable in depth analyses. It was thought that this method would ensure an understanding of problems facing the industry regarding increasing emissions and LCA failures through a natural communicative process (Mack et al., 2005). A series of themes were extracted from the literature and used as prompts for a discursive data collection method. Additionally, the literature was also used to generate three research questions which were used to understand how barriers to sustainability could be overcome to aid the diffusion of low carbon strategy.

The initial data collection was a focus group study. The focus group tested the themes and questions constructed from literature findings. Questions and themes were reformulated from this focus group data to ensure the expert interviews were targeted at the appropriate range of people and the most useful questions were being asked. In order to analyse the data, a content analysis was carried out for both the focus group and the expert interviews. The interviews were then subject to further analysis via the application of institutional theory and diffusion theory. The coding practices used were initially formulated from the key themes extracted from the literature review and furthered during the focus group study, guided by both theories.

1.9 The research questions

The research aim was to address why construction companies were neglecting to use widely available LCA products as carbon emissions increased and how this could be overcome. The research questions were developed to consider how the industry could introduce low carbon decision making processes more easily into projects and what provided the impetus for them to consider emissions. An understanding of this was achieved through assessment of institutional pressure barriers and how these could be overcome to ensure the diffusion of low carbon strategy. The questions were formulated to understand how using DiMaggio and

Powell's (1983) institutional theory and Rogers' (1971) diffusion theory as theoretical lenses could address the research gaps highlighted in the literature. The three questions can be found below.

RQ1. *How can low carbon decision making strategies diffuse throughout the construction supply chain?*

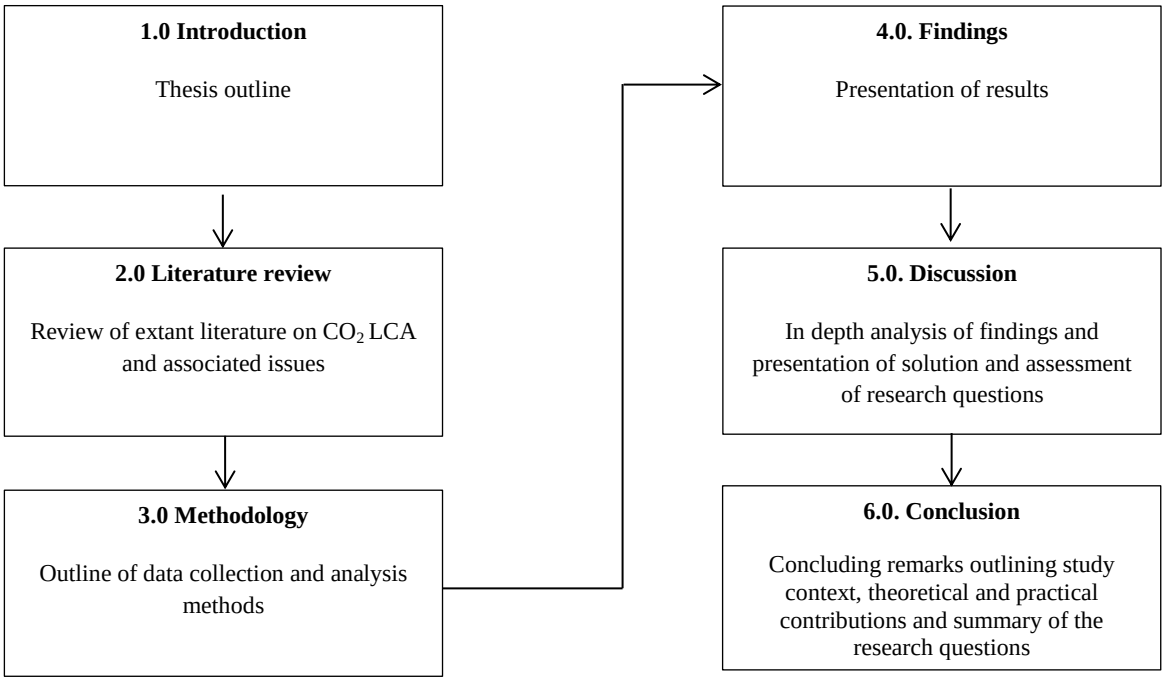
RQ2. *How can low carbon decision making strategies improve a firm's legitimacy in the construction industry?*

RQ3. *What provides the impetus for construction companies to take on low carbon decision making innovations?*

1.10 Structure and research scope

The thesis moves through a series of six chapters addressing each aspect of the research. In chapter 2.0 an assessment of the current literature surrounding supply chain impacts, collaboration and CO_2 life cycle analysis in the construction industry is carried out. Chapter 3.0 moves on to detail the methodology used for data collection with chapter 4.0 presenting the empirical data collected from a focus group and a series of expert interviews. Chapter 5.0 provides an in-depth discussion of the empirical findings and a conclusion is provided in chapter 6.0. The aim of the research was to create an understanding of the potential for increased collaboration throughout the construction supply chain as a perspective for overcoming institutional pressures and encouraging the diffusion of low carbon innovation. It was not the purpose of this research to understand how carbon emissions could be calculated using mathematical formulae. Its purpose was to provide a discussion of a theoretical proposition for how increased collaborative supply chain methods could aid the diffusion of low carbon practices in the wake of institutional pressures. Figure 1.1 provides a diagrammatical breakdown of the thesis structure.

Figure 1.1 Thesis structure



1.11 Chapter summary

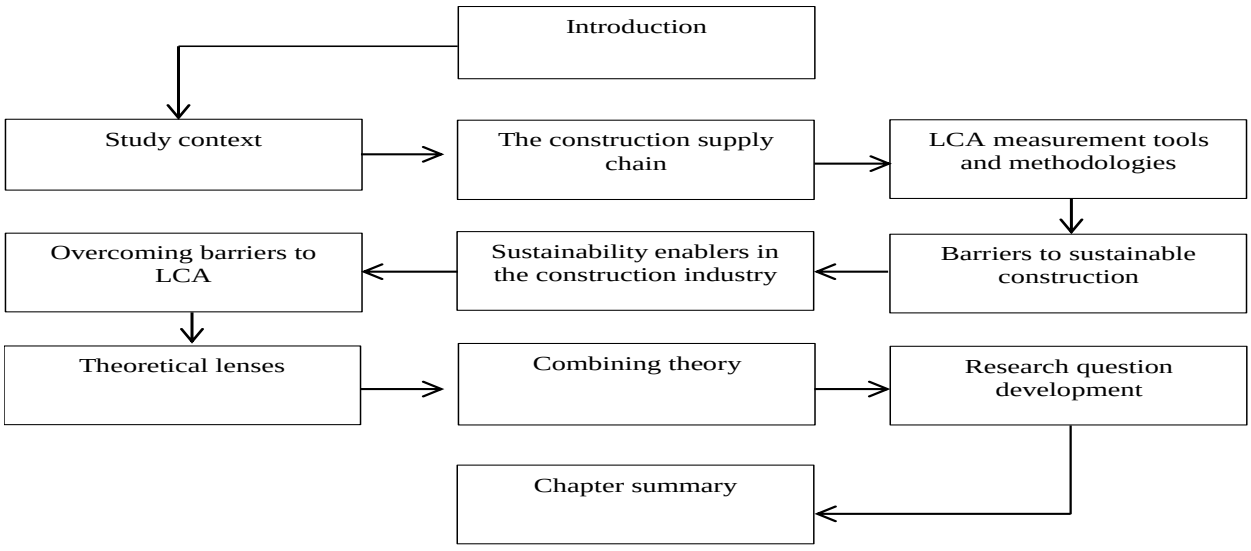
Chapter 1.0 has provided an introduction to the research. It has outlined the background of the study, the research motivation, purpose, significance and the main problem addressed. The design of the research is also outlined and the research questions are proposed in order to provide a contextual setting for the continuation of the research.

Chapter 2.0 - Literature review

2.1 Introduction

One of the most problematic issues for the construction industry and its sustainable practices is the increase in CO_2 outputs (Abanda et al., 2013). Second only to the energy generation industry in terms of emissions, the construction industry consumes approximately 40% of all materials entering the economy, equivalent to 50% of global greenhouse gas emissions (Ramesh at el., 2010). With the threat of increasing global temperatures and rising sea levels, it is becoming increasingly important to monitor and measure emissions in order to understand the anthropogenic impact of CO_2 on the natural world (Parmesan and Yohe, 2003; Jevrejeva et al., 2010). Measurement systems for CO_2 emissions outputs enable decision makers to gain an understanding of which products and/or processes associated with their activity have the greatest impact on the environment. Perhaps the most significant problem for assessing emissions in the construction industry is that despite the vast array of technology available for calculation, emissions are continuing to rise and life cycle technologies are not widely used (Giesekam, et al., 2014; Miozzo and Dewick, 2002; Strategic Forum for Construction, 2010). The purpose of this study is to understand the potential reasons for the seemingly stagnant approach to CO_2 calculation in the industry, which will be achieved by assessing current technologies and methodologies, alongside behavioural impacts. An investigation will be conducted in this research to establish the key sustainability barriers and enablers in the industry. The review of the literature will be assessed by using the following structure shown in Figure 2.1

Figure 2.1 Literature review structure



2.2 Study Context

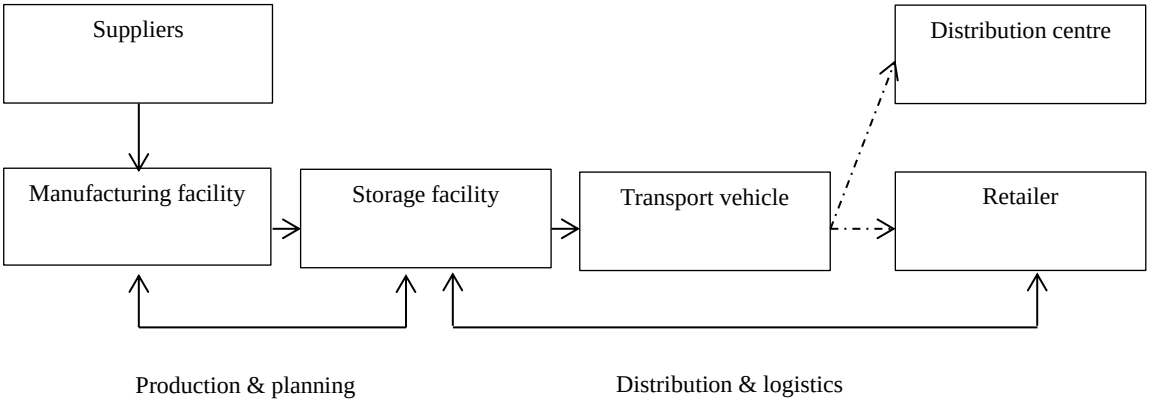
The context of this literature review is based on understanding why emissions are increasing and understanding ways in which emissions could be lowered by assessing the general trends, methodologies, conflicts and gaps in the current life cycle analysis (LCA) literature. The scope of this literature review encompasses both management and building science. The literature covered reviews scientific methodologies for carbon calculation, alongside management and supply chain theories in order to provide an understanding of whether the problem is technology based or rooted in behaviour. The behavioural concept is dealt with by assessing supply chains. Through an understanding of the construction supply chain it is easier to recognise the key relationships which occur throughout a construction project, thus highlighting the areas in which information regarding CO_2 outputs can be shared. The theories used to understand sustainable construction are Roger's (1971) diffusion theory and institutional theory, more specifically DiMaggio and Powell's (1983) concept of institutional theory covering mimetic, coercive and normative isomorphic pressure. These theories provide an understanding of how innovations or new working processes are taken up (diffusion) and how they are affected by institutional pressures (institutional theory).

2.3 The construction supply chain

The lack of specific literature on supply chain relationships which directly affect CO_2 highlights the need to analyse the supply chain itself in order to understand factors which influence these relationships. In order to address the concept of the supply chain in detail, this section aims to cover problems faced in the construction industry with current supply chain models alongside alternative supply chain models which have been applied in the construction industry. Networked, seamless, e-business and maturity models have been discussed to address their application to construction as suitable alternatives. A supply chain can be seen as the process that converts raw materials into final products in an integrated manufacturing network (Beamon, 1998). Cheng, et al., (2001) have put forward a slightly different definition addressing the supply chain as the relationship between buyers and suppliers. Construction supply chains involve all the parties participating on construction projects, including those who extract the raw materials through to the client requiring the building. Figures 2.2 and 2.3 show supply chain diagrams lifted from the literature which highlight construction supply chains. Figure 2.3 is considered to be a typical construction

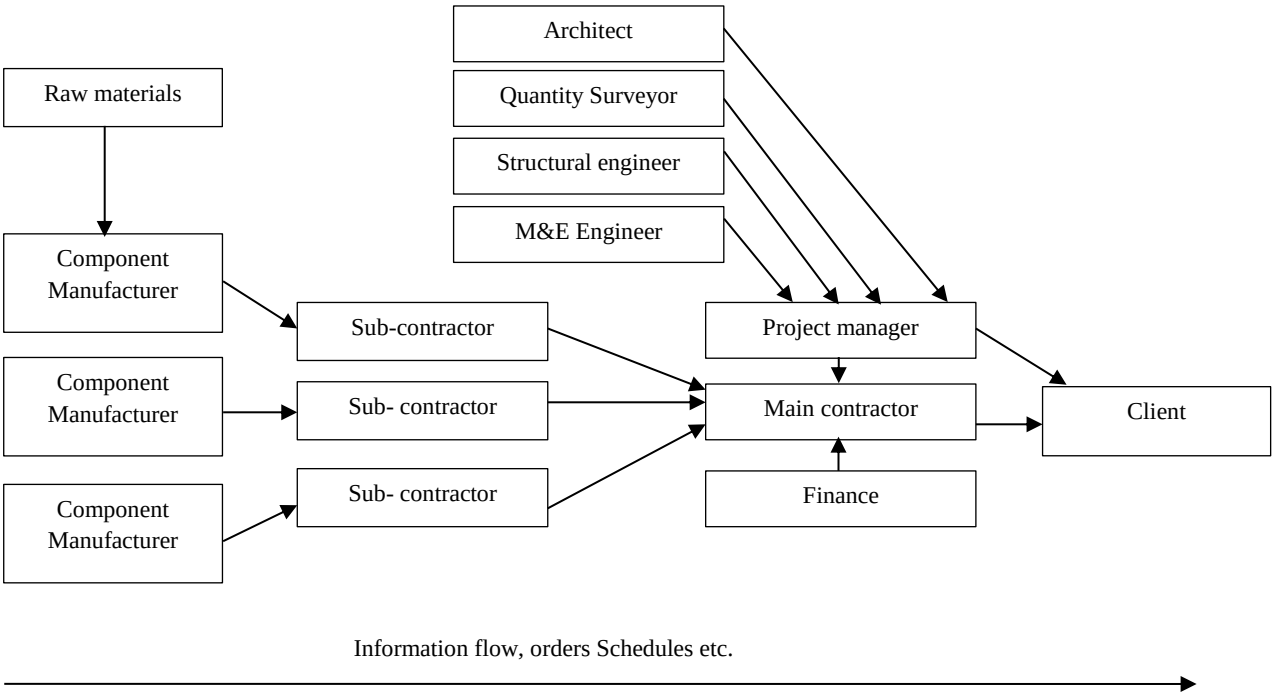
supply chain (Cartlidge, 2009). It simplifies the construction process and enables the reader to understand the key roles within a construction project.

Figure 2.2 Supply chain process



(Source: Beamon, 1998)

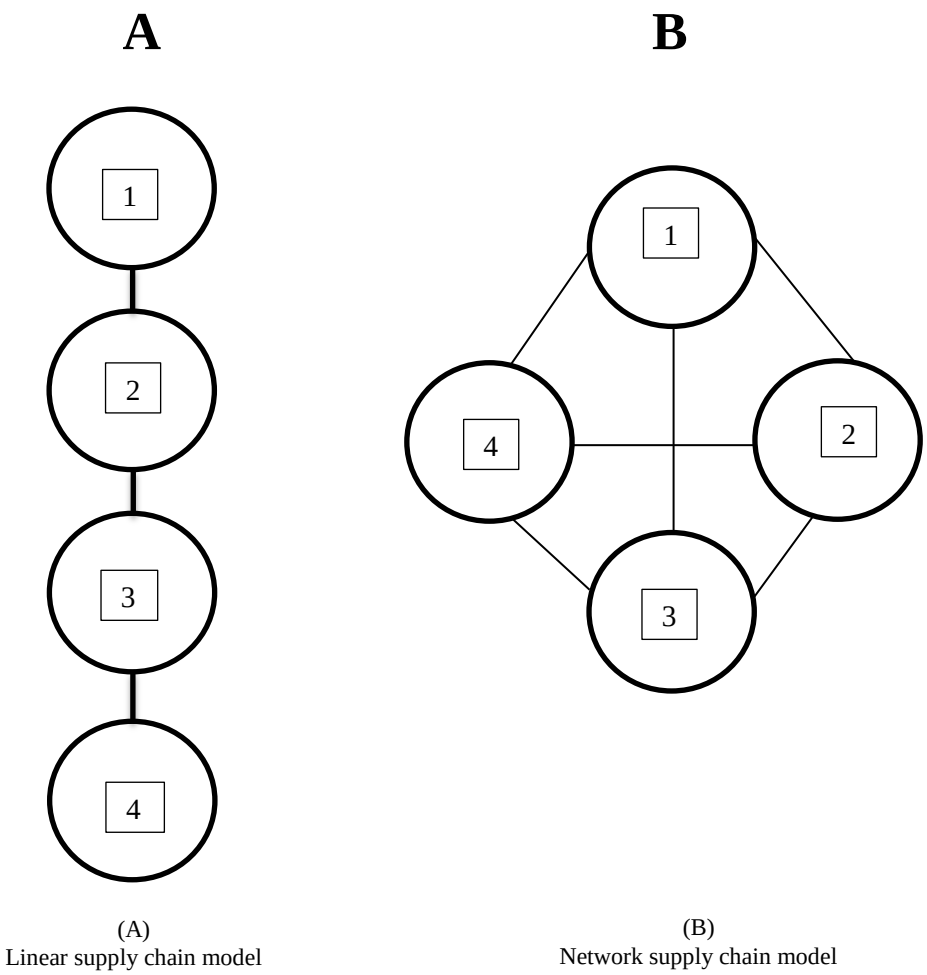
Figure 2.3 A typical construction supply chain



(Source: Cartlidge, 2009)

Despite being widely used, the typical construction supply chain shown in Figure 2.3 is considered out of date for current construction projects as it inhibits collaborative processes (Cheng et al., 2001; Kornelius and Wamelink, 1998; Stock et al., 2000). The arrangement suggests that each organisation in the supply chain is 'individual' and solely responsible for their own duties. In consequence, there is little or no stimulation for improving the relationships between the supply chain actors (Cheng et al., 2001; Kornelius and Wamelink, 1998). Figure 2.4 adapted from Cheng et al. (2001) contrasts the linear processes of supply chains against a 'network structured' supply chain which may encourage greater communication between all actors.

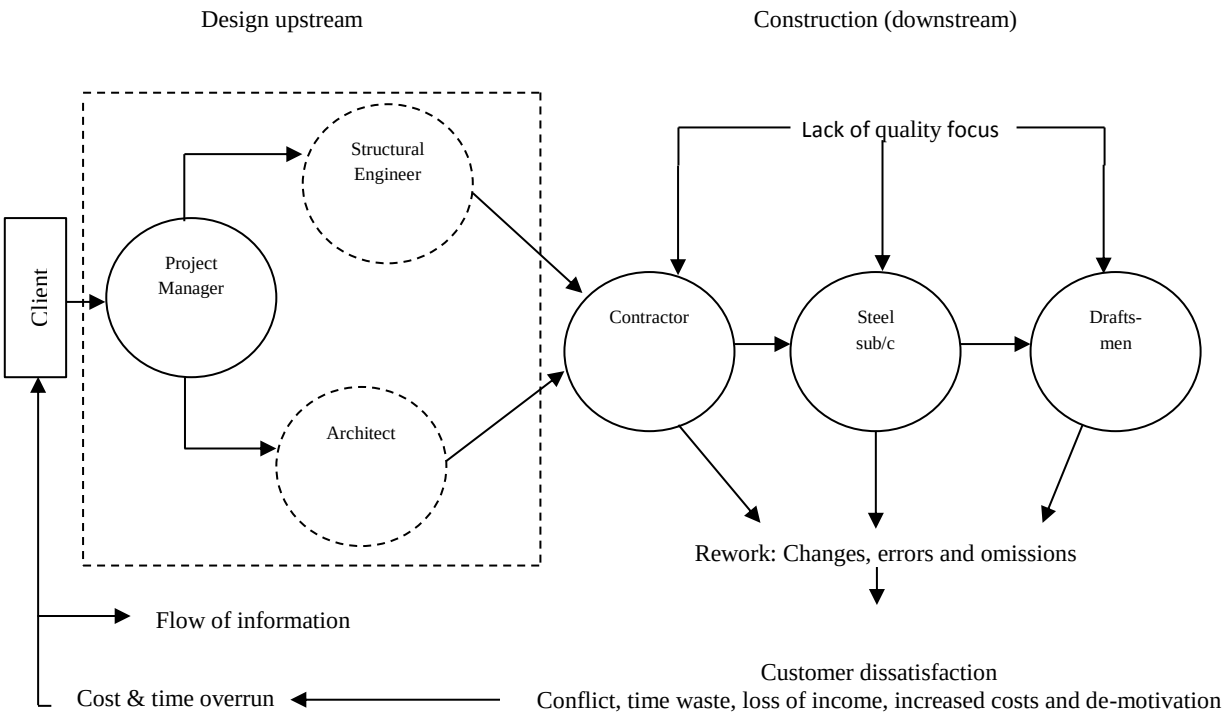
Figure 2.4 Linear and network supply chain models



(Source: *Cheng et al. 2001)*

The tasks within a linear supply chain are generally divided up into specific disciplines (Korneleus and Wamelink, 1998). These disciplines have personal objectives which do not take into account potential impacts that may resonate throughout the supply chain by making particular decisions. Furthermore, in the linear model, the decision making process is said to be fragmented and adversarial with a distinct lack of coordination and communication between participants (Cheng et al., 2001). Lack of coordination often leads to the need for re-work further down the line (Love et al., 1999), reminiscent of the environmental assessment process which is usually retrospective in nature (Poudelet et al., 2010). Figure 2.5 highlights how a lack of coordination and communication affects this process, creating more work.

Figure 2.5 Rework in a supply chain



(Source: Love, et al. 1999)

In construction supply chains information gathering and sharing can be extremely problematic and uncoordinated (Madenas et al., 2014; Love et al, 1996; Kazi and Charoenngam, 1996), resulting in dysfunctional supply chains making information dissemination difficult, increasing costs, errors and wasting time (Love et al., 1999; Cheng et al., 2001; Love et al., 2004).

To resolve dysfunctional and uncoordinated supply chains, network structures in supply chains through partnering have been suggested (Crowley and Karim, 1995). The outlined structure eliminates the core competitive driver and enables a greater sense of communication where key partnerships can be formed. The network based supply chain approach embraces the concepts of cohesiveness, flexibility, collaboration and integration; notions which would be essential for data sharing which could aid low carbon decision making (Lin et al., 2002; Cheng et al., 2001; Love et al., 2004). With the current industry values based on singular achievements and solitary working which is arguably due to the linear and hierarchical supply chain (Korneleus and Wamelink, 1998; Cheng, et al. 2001; Dirix et al., 2013), collaboration has been difficult to implement, suggesting that a reconfigured supply chain could be most beneficial for furthering integrated working approaches.

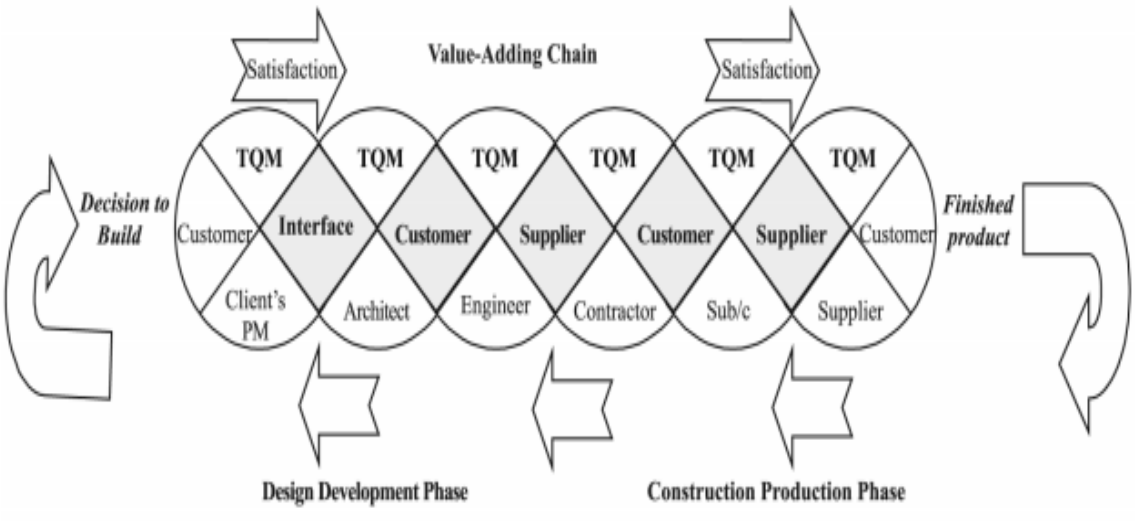
In view of the problems associated with supply chain functionality in the construction industry, it is imperative to understand and explain a series of supply chain models in order to understand why changes are required. Sections 2.3.1 -2.3.5 discusses a series of supply chain models. These models were chosen based on their multidisciplinary working patterns which are essential in construction. They focus on collaboration skills, shared responsibility, integration and teamwork – seemingly lacking components of low carbon decision making in construction.

2.3.1 Seamless supply chain management model

In order to remain competitive, perform and win business some organisations must become part of a number of supply chains (Towill, 1997). A supply chain model which has been developed to aid processes in an environment where all information applicable to the effective operation of a system is available on time, and undistorted is known as a 'seamless supply chain' (Towill, 1997).The seamless supply chain model (Love et al., 2004) encourages relationships throughout the supply chain with a cooperative approach to problem solving. Seamless supply chain models have a horizontal structure with an emphasis on multidisciplinary decision making, somewhat different to the traditional linear supply chain models in use today. The seamless structure enables members of the project to have direct contact with the client during the design and all actors share responsibility for the outcomes of the project. An approach such as this stimulates collective learning, teamwork and aims for a vibrant psychosocial system, seamlessly coordinated rather than a highly competitive system between actors (Love et al., 2004; Ellram and Cooper, 2014). Collaborative

approaches have been the motivation behind studies into redeveloping construction supply chains (see Grove, 1998; Tang, 2001; Egan, 1998), and all are critical of the construction industry's approach to collaborative working. Love et al., (2004) explains the application of a seamless model through the application of Total Quality Management (TQM) as illustrated in Figure 2.6.

Figure 2.6 Customer-supplier interface in the Supply chain



(Source: Love et al., 2004)

Figure 2.6 illustrates how the concept of TQM could be used in the construction supply chain. Rungtusanatham et al. (2015) explain TQM as a method for defining criteria for a range of supply chain processes such as leadership, customer/supplier interface, information exchange, process management and leadership strategy. Merging the concept of partnering whilst simultaneously adopting a TQM strategy could have positive implications for the overcoming supply chain problems (Wong and Kanji, 1998).

Several supply chain systems have been acknowledged and implemented to overcome partnering and collaboration problems (Love et al., 2004) with limited success. As TQM is not a practiced philosophy of construction industries it has been argued that the industry is unable to develop the skills required for improving supply chain practices (Love and Sohal, 2002). The seamless supply chain model relies on a project facilitator who is responsible for overseeing negotiation, monitoring resources used and has the task of evaluating design progress on the client`s behalf (Smith and Jackson, 2000). However, as previously

highlighted, the responsibility for the outcomes is shared (Love et al., 2004). In seamless supply chains the project facilitator is able to develop inter-organisational communication between project parties (Ofori, 2000b).

In the seamless model the project team is not selected based on price, but by weighted pre-qualification criteria such as experience, qualifications of personnel, quality of service provided, quality of management, current workload, strategic alliances, past performance and negotiation (Wong et al, 2001; Li et al, 2001). Price-driven choice can lead to restriction of flexibility of the contractors when it comes to innovative approaches or methods which are considered to provide the 'best' rather than the least expensive (Holt et al., 2000; Walker et al., 2002).

The seamless method of organisation values the use of quality function deployment (QFD) as well as information and communication technologies (ICTs) to eliminate barriers between disciplines, whether they are cultural, behavioural or organisational (Love et al., 2004). QFD provides a structured approach to meeting customer requirements and formulating plans to meet those needs (Chen and Chen, 2014). Members have to focus on customers and QFD is a tool that provides an understanding of the customer`s requirements. Additionally, this can lead to higher levels of commitment and motivation. Teamwork is stressed as indispensable for application to the supply chain as the team is required to understand each other's goals in order to become more customer focussed (Kamara et al., 2000; Love et al., 2004). The notion of teamwork could be highly relevant to the development of the construction supply chain which currently works in individual silos with a lack of collaboration. It is thought that collaborative working strategies are held back by hierarchical supply chains (Rosinski et al., 2014).

The client is not left behind in this model as they participate actively throughout the design process. The facilitator is responsible for arranging a design-planning scheme to ensure that there is a logical sequence for information transfer between members. Previous studies have shown that where there is an independent project facilitator, inter-organisational communication has been effective (Ofori, 2000b). There is still a strong sense of the value of technology in this model which could be extremely useful if the construction industry continues to foresee a technological solution (Kamara et al., 2000).

2.3.2 E-business model for supply chains

E-business has been defined as the exchange of goods, services or communications via electronic channels for the purposes of conducting business (Costello and Tuchen, 1998). IT is used to pass information between organisations within a supply chain involving numerous supply chain actors in the construction industry (Cheng et al., 2001). The e-business model has a virtual network structure used to improve communication, coordination and encourage mutual sharing of inter-organisational resources and competencies. E-business supply chain models are built around planning and execution of the front and back end operations in a supply chain using the internet (Lee and Wang, 2001). Technology requires adaptations and changes not only in processes, but in the whole organisation. The notion of using technology as a means of understanding the supply chain correlates with the construction industry's thirst for technological advancement, particularly in the area of CO_2 data collection as evidenced by the focus on technology in academia (Adelberth, 1997; Adelberth, 1999; Abanda et al., 2013; Alyami et al, 2013; Baek et al., 2013). One of the key challenges with this model is that extra capital is required as the software needs to be purchased and staff need to be trained (Clarke and Wall, 1998; Cheng at al., 2001; McCreadie and Rice, 1999). A barrier to the implementation of CO_2 lifecycle data products is the education and training required to use them (Janda, 2011). Although this model undoubtedly shows promise, the fact that the construction industry is generally conservative, focusing on tested methods (Blayse and Manley, 2004) may prove to be problematic for its implementation.

The e-business supply chain model is useful for increasing collaborative processes as its core values lie within networked supply chains, collaboration, change management and adaptation (Lee and Whang, 2001). Information sharing is vital to ensure that the supply chain is driven by the consumer`s demand. It is also a way of avoiding the bullwhip effect which occurs when demand information is distorted (Forrester, 1961). The bullwhip effect usually occurs when local information is used to make demand forecasts and then passed to upstream partners who then disseminate the information to other levels. The distortions are amplified from one level to another in a supply chain and are recognised as one of the main reasons for inefficiencies in supply chains (Lee and Whang, 2001).

E-business models also help to facilitate the exploration of innovative IT, since there is a cooperative environment allowing access to more confidential information due to constant discussion in groups and active participation (Cheng et al., 2001). A collaborative

environment is something which could be useful for communication regarding CO_2 reduction as supply chain actors can readily access the information required to make low carbon decisions more easily. To achieve improvement in project performance, the traditional structure has to be changed. If this occurs, collaboration and inter-organisational teamwork can be integrated into the system which is key to project success (Albanese, 1994). It is argued that the adoption of this method can result in efficiency improvement and enhanced customer responsiveness (Lee and Whang, 2001). As technology is important in the e-business model it is vital that the employees accept and understand the tools chosen (Mukherji and Mkherji, 1998). Thus, the importance of the value of the technology used must be exposed to everyone and changes in organisation are imperative for improvement (Cheng, et al., 2001; Lee and Whang 2001). However management and employees have to actively work on the implementation of such an approach. It is suggested that change must occur from the top management to the other employees, using a top-down supply chain method (Rosinski et al., 2014; Dirix et al., 2013).

2.3.3 Construction supply chain maturity model

A further supply chain model which has been assessed is the maturity model. Processes have maturity life cycles and there is a correlation between improving process maturity and business performance (Vaidyanathan and Howell, 2007). Processes have life cycles or developmental stages that can be clearly defined, managed, measured and controlled throughout time improving performance (Lockamy and McCormack, 2004).The maturation of processes appeases institutionalisation, consistency of outputs, reduction of conflicts and encouragement of cooperative behaviour (McCormack and Johnson, 2001; Vaidyanathan and Howell, 2007). The following are two examples of maturity model use:

i. Capability Maturity Model (CMM): from Carnegie Mellon University, it is one of the most widely used models, originally developed for engineering software (Paulk, 1995). It has specific benchmarking tests to determine the current level of maturity for a company. The actions to improve the maturity are also specified. Its certification is similar to an ISO-9001[1], and is a way of having expectations of a software development organisation (Nightingale and Mize, 2002). The first attempt at applying the CMM maturity model to the construction industry occurred during the SPICE project, a university funded research

[1] Quality management standard to ensure that products and services meet customers' needs consistently (ISO-9000, 2015)

programme which assessed the success of CMM and evaluated whether this can be applied to the construction industry (Sarshar et al., 1999). Surveys, case studies and questionnaire data were gathered in order to understand the potential for maturity application. The conclusion of this particular research was that the CMM model could not be directly applied to the construction industry. It was thought that this was the case because CMM is applicable only to single organisations and did not capture the multi-organisational nature of the construction supply chain (Vaidyanathan and Howell, 2007).

ii. Project Management Process Maturity Model (PM^2) is a concept that adopts the process and functional model developed to benchmark various actors who do project based business (Kwak and Ibbs, 2002). The model recognises that as companies mature in their project management techniques, they move away from fixating on single functions to manage solitary projects towards the management of numerous projects on an integrated level (Vaidyanathan and Howell, 2007). Maturity models all have the same principles but when they are applied to a particular industry, the characteristics of the industry are encapsulated, which provides more information for an oriented roadmap that ultimately helps participants to achieve process maturity (Vaidyanathan and Howell, 2007). Aspects of this model have potential application to the construction industry which currently work individually on set tasks (Abbott, 1988). Such a model could provide an indication of how collective working may be applied in construction supply chains.

The main problems encountered with the prospect of using maturity models in this research was that firstly they appease institutionalism, which could present a significant barrier to the development of low carbon innovation. The implementation of new technology requires change and innovative processes to occur. Secondly it works on the maturity or development process of a business which is often short lived in construction due to short term contracts. Therefore development maturity cannot be established over a long period of time (Dubois and Gadde, 2002). Furthermore it is also heavily based on the improvement of performance and so it may not be easily applicable to the complex nature of sustainability, which is often not driven by finance (Sarkis et al., 2011). Finally, use of the model has indicated that it is more suited to single organisations and although collaborative approaches are favoured, it is not easily applied to large supply chains consisting of many organisations (Vaidyanathan and Howell, 2007). Therefore its application to multidisciplinary environmental activities is most likely unsuitable (Kiker et al., 2005).

2.3.4 Green and sustainable supply chains

Increasing concern surrounding environmental issues has encouraged academia and industry to address green and sustainable supply chain models in the wake of growing energy costs and consumer awareness of social, environmental and economic business impacts (Sarkis et al., 2011; Carter and Rogers, 2008). Sustainable supply chain management can be defined as the management of information, finance and communication between companies within the supply chain, whilst taking into account economic, environmental and social outputs of business activities i.e. the triple bottom line (TBL) (Seuring and Müller, 2008; Sajjad et al., 2015; Elkington, 1997). Green supply chain management goes slightly further; it combines environmental practices with traditional supply chain concepts (Kumar et al., 2014), considering both upstream and downstream operational processes (Carter and Ellram, 1998; Kumar et al.. 2014). The notion is to encompass guidelines and practices adopted by businesses to reduce their negative impacts on the environment (Zhu et al., 2008). The adoption of a green supply chain model is often a fundamental element of an organisation's strategy to move towards an environmentally sustainable business model (Zhu et al., 2005).

The implementation of such supply chains has been mixed in terms of acceptance and success. Some have viewed the implementation of green supply chains to be beneficial to business, decreasing costs, improving overall performance and even improving a firm's reputation (Carter et al., 2000; Hervani and Helms, 2005; Wycherley, 1999). Others view the implementation as a reactive public relations exercise to governmental pressure increasing 'greenwash' rather than truly sustainable practices (Porter and Van de Linde, 1995; Greer and Bruno, 1996; Walker et al., 2008). Green and sustainable models do not solely focus on the economics of business but seek to encompass industrial development issues such as waste disposal and recycling. In this system the life cycle of products is integrated in to a more wide-ranging supply chain procedure (Sheu et al., 2005).

Despite its considered importance in supply chain development, the implementation of green supply chains is notoriously complex, particularly due to the inter-organisational product life cycle analyses required (Aref et al., 2005). It is also problematic to manage the undertakings of all supply chain actors, which includes product specific logistics distribution networks and equivalent reverse-logistics channels and coordination. There are very few appropriate models to aid with the management of logistic flows between supply chain actors in green or sustainable supply chain management (Sheu et al., 2005). In addition, external factors such

as governmental policies and customer behaviour will also affect green supply chain performance (Walker et al., 2008; Srivastava, 2007; Zhu et al., 2008). The nature of green and sustainable supply chains is complex and the implementation of a framework which could accommodate many different factors such as logistical flows, customer behaviour, product lifecycles and governmental policy is difficult (Sheu et al., 2005). Additionally, it often requires a form of LCA technology to complete all aspects of environmental assessment (Zhu et al., 2008) which is notoriously difficult to implement.

A multiple attribute utility theory approach to lean and green supply chain management was found in Kainuma and Tawara (2006). The paper proposes a new approach to supply chain scope in order to include re-use and recycling throughout the life cycle of products and services. In this model, new metrics have been proposed by using a multi-attribute framework. Traditionally return on asset (ROA) has been used; however in this case the new metric is LCA, measuring both environmental and social supply chain effects (Kainuma and Tawara, 2006). The implementation of this new metric provokes a movement away from the sole focus of monetary gain towards a greater focus on environmental and social protection, a similar prospect addressed by the triple bottom line approach (Elkington, 1997); a concept gaining favour in construction.

2.4 CO_2 life cycle analysis (LCA) - measurement tools and methodologies

In order to understand the implementation of life cycle analysis (LCA) products and processes, it is essential to understand how they operate and what is currently available in the industry. Understanding the methodologies will enable a clear assessment of how data for calculation is gathered, shared and how these methods are applied in currently available calculation tools. Addressing how the tools function could further an understanding of the problems faced with implementing such technology in the industry, and whether the core problem with low carbon innovation was in fact the result of a technological or behavioural issue.

Life cycle analysis (LCA) is a procedure used for addressing the environmental impact of a product throughout its entire life cycle. It takes into account the environmental consequences of all activities relating to that product, from the extraction of raw materials, through to manufacture, use, end of life treatment, recycling and disposal (ISO 14040, 2006). The concept of life cycle analysis has been an area of interest in the construction industry as far

back as the 1980s (Bekker, 1982). LCA had been in existence since the 1960s in a much simpler form (Guinée et al., 2010; Buyle et al., 2013) however it had not been applied in the construction industry prior to 1982. Bekker's (1982) study was not well received as it was argued at the time that the LCA approach lacked sufficient scientific grounding that prevented the life cycle tool from being accepted in the industry (Guinée et al., 1993; Buyle et al., 2013). Consequently, LCA and the environmentally responsive construction approach is still struggling to gain momentum in the industry (Pulaski et al., 2006; Lin et al., 2012).

Supported by the vast amounts of new technology that have emerged LCA has improved scientifically over the last 30 years and is able to achieve more through process analyses, economic input-output and hybridised methods of mathematical calculation (Joshi, 1999; Poudelet et al., 2012; Crawford, 2008). Tools such as IMPACT, ELODIE, GaBi, BEES, SimaPro, Life Cycle Explorer and the Athena Impact Estimator are the product of increased interest in emissions calculation tools. Despite methodological improvements no significant product uptake rates have been achieved suggesting that the software may not have improved (Chevalier et al., 2009; Singh et al., 2011; Pieragostini et al., 2012; Norris and Yost, 2001; Hischier, 2011). All technology created for the purpose of measuring CO_2 emissions has the capacity to aid low carbon decision making by providing mathematical calculations for CO_2 outputs of buildings and or building products. Despite the existence of such technology CO_2 levels are continuing to rise in the construction sector (Strategic Forum for Construction, 2010) signifying perhaps that technology itself is not the only barrier to lowering CO_2 emissions in the industry.

It is claimed that one reason for increasing emissions despite technology availability may be the myopic view adopted during construction projects. Only those directly involved in the on-site project have any control over emissions calculations and decision making. Therefore supply chain impacts will often be disregarded as the focus remains on site activities and rough estimates of highly impactful processes (Koh et al., 2013; Vrijhoef and Koskela, 2000). Construction projects often have complex supply chains which involve many actors and so therefore to have a true understanding of building emissions, it is important to involve all key supply chain inputs in low carbon decision making which could be achieved via collaborative supply chain working (Benjaafar et al., 2013).

The critical challenge for the construction industry is how to manage lifecycle data collaboratively throughout the supply chain, in order to make low carbon decisions

throughout a project's lifecycle (Kurul et al., 2012). Using a supply chain approach to carbon calculation would require greater integration of supply chains and collaborative decision making processes (Benjaafar et al., 2013; Koh et al., 2013). One of the most visible issues with existing technology and software is that the majority of carbon calculation tools are solely focussed on the firm using it (Koh et al., 2013). With the exclusion of broader supply chain inputs in favour of the user (the firm), the benefits of collaboration between key supply chain actors has been missed (Koh et al., 2013). Consequently a focus on the supply chain could present benefits to carbon calculation through data sharing processes. The identification of this shortcoming addressed by Koh et al. (2013) has provided the impetus to look towards the potential benefits of a more holistic approach to LCA, which provides grounding for this research.

2.4.1 Significant scientific developments in CO_2 LCA

The most noted technological development in the industry which has occurred through the use of LCA has been improved building performance (Li et al., 2013a). Technological advancement in low energy building products has increased significantly in the last decade due to the introduction of technologies such as solar panels, ground source heat pumps and biomass boilers amongst others. Interest in operational efficiency and low carbon technology has led to a growing body of research in zero energy buildings (Torcellini et al., 2006; Marszal et al., 2011) and low energy buildings which rely heavily on renewable energy sources (Dawood et al., 2013). It is due to the use of such technologies that the operating energy of a building has decreased starkly in recent times (Crowther, 1999; Sartori and Hestnes, 2007: Ding, 2008; Dixit et al., 2010; Ramesh et al., 2010). Increases in the use of energy efficient technologies has increased the embodied CO_2 in buildings due to the high energy manufacturing processes of complex materials such as silicon wafers in solar panels (Sherwani and Usmani, 2010). The consequential increase in embodied CO_2 outputs in building construction has encouraged embodied CO_2 studies (Thormark, 2006; Dixit et al., 2010; Monahan and Powell, 2011; Chang et al., 2012; Jaio et al., 2012) all of which have focussed on the calculation of embodied energy in buildings. As much as 60% of the primary energy can be used in the production phase (Gustavsson and Joelsson, 2010), a lifecycle phase which was previously thought to be negligible in the building lifecycle. The acknowledgment of the importance of tracing carbon has provided the impetus for this

research to use a supply chain approach for understanding associated carbon emissions in buildings.

General trends in construction LCA literature have been predominantly focussed on CO_2 calculation methodologies with little or no regard for collaborative decision making inputs (Erlandsson and Borg, 2003; Ding, 2008; Haapio and Viitaniemi, 2008). Acknowledgement of the lack of research in this area has moved some scholars towards the analysis of behavioural elements of CO_2 calculation. Kyrö et al. (2012), for example assessed management styles in housing companies which affect CO_2 outputs. Research on the management of carbon data, calculation and the way in which the collaboration process throughout the supply chain affects CO_2 emissions is lacking in construction. Supply chain integration and stakeholder collaboration has been explored (Dainty et al., 2001; Briscoe and Dainty, 2005; Orlander, 2007; Bal et al., 2013) its application to CO_2 emissions remains elusive in the literature. The balance between theory and technology is notoriously difficult however an analysis of existing methodologies is timely.

2.4.2 Calculation methodologies

The abundance of existing LCA products and lack of uptake does not mean that there is no potential for further development of technology. The total life cycle analysis software market appears to be underdeveloped in comparison to the single phase product market[2] (Khasreen et al., 2009; Dixit et al., 2013) . Most software has the ability to cover single products however, there is a lack of software which can cover the entire building lifecycle (Erlandsson and Borg, 2003). There appears to be a lack of client demand for such products in the construction industry that is highly focussed on cost rather than environmental concern (Yang and Chen, 2015; Wigglesworth, 2012). Level one models are product based, whereas level two models theoretically have the capacity to measure total life cycle CO_2. All currently available software is based on one of three embodied CO_2 analysis models (below) which are discussed in detail in sections 2.4.3 – 2.4.5.

- **Process based analysis.** The process based LCA method calculates emissions by assessing energy requirements, and the subsequent emissions from the main processes of product creation using inventory data. The system boundary i.e. what is included and excluded in the process is decided by the analyst (Lenzen and Treloar, 2002)

[2] A single phase LCA product has the capacity to calculate the emissions outputs of single products rather than a complex building system.

- **Economic input output analysis (EI-O).** Economic input-output analysis is a method of carbon calculation which uses economic input-output tables with environmental data. It describes the interdependencies within industries to trace carbon outputs at a sectoral level. The system boundary is the economy (Lenzen and Treloar, 2002.)
- **Hybrid analysis (Bullard et al., 1978).** A hybrid analysis incorporates both process and economic input output methods. For example, the process method may be used to calculate all direct emissions from the construction of a building (i.e. the construction phase) and the E-IO method could be used to calculate indirect emissions (i.e. the manufacturing phase) or vice versa.

Assessments of all three models exclude a wider understanding of the importance of communication between supply chain inputs (Thormark, 2000; Menzies et al., 2007; Khasreen et al., 2009; Buyle et al. 2013). The issue is not simply the number of assessment methods but the lack of agreement on which model should be used on a project. If discussions take place from the conception of the project, decisions regarding standard methodologies can be made. There is also inconsistency as differing methodologies of embodied calculation appear incomplete or simply inaccurate (Dixit et al., 2012). Essentially the same building can produce three different embodied readings by using the three different assessment methods. All models focus on mathematical formulae (Trealoar et al., 2001). Models lack an understanding of the decision making process, which could be aided by understanding the supply chain. It is argued that the supply chain is the route to understanding carbon inputs (Benjaafar et al., 2013). Moving towards a behavioural low carbon decision making approach by using the supply chain could aid the understanding of construction project relationships which directly impact on carbon outputs.

2.4.3 The process based model

The process-based model is considered to be one of the most widely used methods of CO_2 lifecycle analysis and has been used or reviewed in many studies (Lenzen and Treloar, 2002; Dixit et al. 2010; Rossi et al. 2012 and Poudelet et al., 2012). Despite its use in such LCA tools as the Athena Impact calculator, Envest and Eco-Invent software the model excludes many processes and has associated difficulties with the system boundaries (Alcorn and Baird, 1996; Lave, 1995; Dixit et al., 2010; Li et al., 2013b). A process analysis of LCA can have

an error of as much as 50 per cent (Dixit et al., 2010; Crawford and Treloar, 2003), meaning half of all of the data could potentially be incorrect. Errors of this scale are problematic when process analysis data is used in accessible databases such as EcoInvent. The EcoInvent database is an international life cycle inventory system outlining common CO_2 material outputs. It is utilised by researchers and industrial companies and also used in conjunction with calculation tools such as Simapro. Work conducted by those who LCA software in industry or academia suffer from the same error which is repeated (Treloar et al., 2001; Crawford and Treloar, 2003; and Ding, 2005).

Despite its flaws, process analysis can be relatively successful as single product evaluation method when used in conjunction with strict guidelines such as PAS -2050[3] (Crishna et al., 2011). Research by Crishna et al. (2011) is a good example of how process analysis can be used successfully for a product; in this case dimension stone. Their study uses strict regulations combined with clearly formed system boundaries, providing a positive contribution to process analysis research. No other model is capable of providing such an in depth analysis, although it is difficult to achieve, the possibilities with this model and its ability to trace back to the roots of CO_2 is unique (Crishna et al., 2011). A process enabling such in depth analysis requires significant data from all construction stakeholders which is often difficult to obtain, primarily because analyses are often carried out retrospectively (Poudelet et al., 2012). The use of retrospective analysis could be in part due the fact that most collaboration during any construction project occurs during the design process. Design occurs at a very early stage in construction and gaining information after this point can be problematic (Basbagill et al., 2013).

2.4.4 The economic input output model (I-O)

The economic input output model is a CO_2 calculation methodology that requires an understanding of the power influences in a project. The economic input output model is applicable to communication and data sharing systems as it uses economic information to map influential supply chain relationships (Chang et al., 2012). The method addresses some of the problems associated with the process model as it able to use the economy as a system boundary (Chang et al., 2012). It can take into account most direct and indirect energy paths in a project, which is achieved through the use of economic data flows (Fay and Treloar,

[3] Embodied carbon standard specifying requirements for the assessment of the LCA of greenhouse gas emissions of goods and services (PAS-2050, 2011)

1998; Dixit et al., 2010). The model is based on the economic input output matrix (Leontief 1966; Chapman, 1974; Wright, 1974). Each sector produces input/output tables which are made available to national governments. Most national statistics offices within government departments have collected this data for over 40 years; therefore the information is readily available (Liu et al., 2012). The economic flows of each industry are transcribed into energy flows (Alcorn and Baird, 1996; Pullen, 1996; Fay and Treloar, 1998; and Ding, 2005).

The I-O model has major advantages over the process based model as it can accommodate the whole economy as a system boundary, thus incorporating with ease a much larger number of processes than the process model alone (Chang et al., 2012). Studies using this method rely on the economic relationship of each sector being facilitated by supply chain mapping particular products. Difficulties arise when applying this to buildings due to material complexities. Studies such as Hendrickson et al. (2006) have argued that this method makes it feasible to account for total energy consumption which allows for the analysis of each lifecycle phase. Others such as Pullen, (1996); Fay and Treloar, (1998); Pullen, (2000); Treloar et al. (2001); Crawford and Treloar (2003); and Dixit et al. (2010) have disagreed with this due to the aggregation of sectors and the homogeneity of nations which create boundless assumptions and unreliable data. Not every economy works in the same way and project influences will change.

2.4.5 The hybrid model

In order to eliminate inaccuracies in LCA, attempts have been made at the successful integration of both process and I-O models in a hybrid methodology. The aim of this method is to eliminate the errors found in both process analysis and Economic I-O analysis by combining the best features of both (Alcorn and Baird, 1996; Suh and Huppes, 2005). It is thought that this model has the most complete system and its popularity has soared in recent times (Li et al., 2013b; Suh and Huppes, 2005; Crawford, 2008; Strømman et al., 2009). The hybrid method is relatively flexible as it allows the analysis to combine both process and economic I-O methods in different ways. Any hybrid analysis will either have a process or Economic I-O base depending on the requirements of the assessment (Treloar, 1998; Dixit et al., 2010).

The process based hybrid analysis was first seen in the literature in the 1970s (Bullard et al., 1978). A process method is used for both the use and disposal phase of an assessment and

any other important or remaining upstream processes which may be present (Suh and Huppes, 2005). The economic I-O method is then used to account for any remaining processes. The first in-depth process hybrid analysis can be traced back to 1993 in the automotive industry, where the CO_2 lifecycle emissions and impact for cars was assessed from raw material extraction to disposal (Moriguchi et al., 1993). A further in-depth analysis of this method can also be found in the freight transport industry (Marheineke et al., 1998) and has since gained momentum in construction (Bilec et al. 2010; Chang et al., 2012 and Goggins et al. 2010).

The process hybrid analysis should provide relatively complete results providing that the process inventories are correct and that the system boundaries are weighted correctly. It is thought that errors can still occur using this method if key processes are modelled on input output based data which has been aggregated for I-O tables (Suh and Huppes, 2005). Specifically double counting can occur as some of the process based data is also included in the I-O data and so must be subtracted to avoid errors (Acquaye et al., 2008). The hybrid model suffers from the same limitations as the pure process model, as essentially the researcher is relying on inventory systems which may be incomplete (Goggins et al., 2010; Crawford and Treloar, 2005).

2.4.6 The economic input/output (E I-O) hybrid model

The economic input output hybrid analysis uses economic I-O assessments for the base calculation, filing in data gaps with process analysis data. The model works on a system of effectively disaggregating the sectors in the economic input output tables (Treloar et al., 2001; Suh and Huppes, 2005). By breaking down the sectors and replacing them with accurate process data a comprehensive analysis emerges with a reduction in output assumptions (Treloar et al., 2001). The I-O analysis can identify which are the most important direct and indirect energy inputs for a building, from which a process analysis can be applied to produce CO_2 readings (Dixit et al., 2010; Treloar, 1998; Joshi, 1999; Kyrö et al., 2011; Kyrö et al., 2012).

There has been debate around which hybrid model is more efficient for building CO_2 lifecycle analysis. Alcorn and Baird (1996), Crawford and Treloar (2003) and Langston and Langston (2008) have argued that the I-O hybrid model for CO_2 analysis is the most accurate model for a building. In comparison Suh et al. (2004) and Suh and Huppes (2005) have

argued that although the I-O elements of the analysis are useful, they still require a significant amount of process data to be completed and overall the process model has been much more effective at carbon analyses for products. The argument is that a building is a product regardless of complexity. Analysis of a building as a product requires up-to date and accurate data inventories and or economic input output tables.

The decision about the model rests on the individual conducting the analysis and the information that they have sufficient access to. The individual has a significant effect on the recording and assessment of CO_2 outputs in the construction sector through the choice of model and data used (Junnila and Horvath, 2003; Ding, 2005). Any analyst, in academia or industry, will perhaps not choose the best method or even the most widely used. They will choose a relevant model or tool based on the output, objective, scope, resource and time scale; all of which creates significant problems for standardisation in the construction industry as a whole (Suh and Huppes, 2005; Li et al., 2013).

Tool and strategy selection could potentially be improved by a network of collaboration. Data sets and processes are shared to promote an industry standard as most problems in the construction industry are thought to be resolved through effective supply chain collaboration i.e. discussions on effective LCA tools (Cheng et al., 2001; Love et al., 2004). Decision making processes in carbon calculation have been found to be complex. The key strengths and weaknesses found in the methodologies have been summarised below in table 2.1 to highlight the core failings in current LCA analyses.

Table 2.1 Strengths and weaknesses of CO_2 LCA calculation methodologies

Methodology	Key strengths	Key weaknesses	Supporting references
Process	Recognised as the most accurate methodology In depth analysis possible with this method Useful for calculating the CO_2 related to single products	System boundary difficulties Process error of up to 50% Difficult to use with complex products i.e buildings.	(Alcorn and Baird 1996) (Treloar et al., 2005) (Crawford and Treloar, 1995)
Input/output model	Enables supply chain mapping to understand relationship influences Capable of taking into account most direct and indirect energy flows in a project High levels of data based on economic matrices making the	Aggregation of data Assumes homogeneity of nations, which is not correct Often treats imported goods as domestic good, no distinction therefore data outputs are distorted	(Fay and Trelaor, 1998) (Liu et al., 2012) (Dixit et al., 2012)

Methodology	Key strengths	Key weaknesses	Supporting references
	economy the system boundary	High levels of assumptions are made about scope of calculation	
Process based hybrid model	Integration of hybrid model an economic input output theoretically eliminates errors Considered to be the most complete method as what the process based method misses the economic input output model will cover.	Suffers with the error from both methodologies Relies on process inventories which can suffer significant error	(Suh and Huppes 2005) (Goggins et al. 2010)
Economic input/output hybrid model	Uses process model to disaggregate Economic input output data so is able to provide in depth analysis Reduction in assumptions which can be problematic in other methodologies	Still require large amounts of process data which rely on inventories which could be inaccurate	(Suh and Huppes, 2005)

The key themes extrapolated from the assessment of all methodologies have centred on the levels of assumptions, scope, boundaries, software choice and the barrier of traditional construction values, supported in both scientific and management literature (Verbeeck and Hens 2010; Williams, et al., 2012; Stern and Aronson, 1984; von Medling et al., 2013). The supporting literature on a technological and social level indicates that there may be potential benefits for an amalgamation of the two research areas.

2.4.7 Building Information Modelling (BIM)

A further software advancement in the construction industry is the development of Building Information Modelling (BIM). Primarily considered as a product for construction efficiency it could also have an impact on the ability of construction projects to manage their carbon outputs by accurate measurement of product volume (Azhar et al., 2009). According to the makers of BIM:

> '*BIM is a process that involves creating and using an intelligent 3D model to inform and communicate project decisions. Design, visualization, simulation, and collaboration enabled by Autodesk BIM solutions provide greater clarity for all stakeholders across the project lifecycle'* (Autodesk, 2013, para 2).

BIM is seen as a revolutionary development which could have a significantly positive impact on the construction industry both economically and environmentally (Azhar et al., 2009). BIM is not only a technology but also a communication process (Hardin, 2011). Collaboration is believed to be essential in integrating processes and managing information in the construction sector. It is thought that a lack of integration and collaboration between stages of the supply chain often creates waste, impacting on carbon outputs (Coelho and Novaes, 2008; Singh et al., 2011). Waste can be avoided by coordinating projects through BIM by using it as a tool for information exchange and collaboration (Crespo and Ruschel, 2007).

The process aspect of BIM generates and manages building data enabling those invested in the building project to exchange information in 3-D models (Thomassen, 2011; Singh et al., 2011). Information about the project can be stored digitally, making recapture of information possible and easily accessible. If one component in a building project changes, this change can be addressed by all parties involved in the project allowing for easy information exchange (Addor et al. 2010; Thomassen, 2011). A discursive environment allows for participation, collaboration and cooperation in all aspects of the building project (Coelho and Novaes, 2008; Andrade and Ruschel, 2009).

The notion of BIM being both a technology and a process could be its most beneficial and interesting contribution to sustainability. Whilst the technology aspect enables the supply chain to visualise the end product and see how changes can affect the outcome, the process enables the management of this. It allows all parties to collaborate, integrate and discuss changes making both economic and environmental improvements from the design stage onwards. Early decision making is important for sustainability as a large proportion of life cycle impacts are essentially formulated at the design stage (Cofaigh et al., 1999; O'Sullivan et al., 2004; Tsai et al., 2011; Basbagill et al., 2013). By having all key supply chain actors involved from the conception of the project, increased collaboration has the potential to make low carbon decisions easier as information is disseminated throughout the supply chain more effectively (Cheng et al., 2001). Additionally it is thought that the supply chain driver for BIM will have to come from the client who is highly influential in the chain (Eastman et al., 2011). It is also argued that costs and external support often plays a large role in BIM implementation (Bryde et al., 2013).

It is important to address the concept of BIM due to its expected impact on the construction industry. Its potential as a means of information sharing is a particularly useful addition to the concept of communication flow among supply chain actors. Two of the core drivers of diffusion theory are collaboration and communication (Rogers, 1971). Communication between companies encourages new innovations to diffuse throughout an industry, thus making it common practice. If BIM could present itself as a key addition to the sustainability effort for carbon calculation, it could act as a basis for communication flow, eradicating the need for the retrospective environmental assessments.

Sustainability and carbon calculation are not at the forefront of BIM technology (Bynum et al., 2012). The primary focus for BIM appears to be on cost reduction and building efficiency (Interdonato, 2012). Sustainability can be built into the system and a new wave of life cycle analysis products such as IMPACT has been geared towards BIM integration. Sustainability can be developed through the use of BIM software by extracting assessment data from the BIM model. In sustainability decisions, a multidisciplinary approach to environmental aspects of the project is often required (Kiker et al., 2005). BIM could provide a collaborative approach by formulating a platform for project members to manage and make decisions in their specialisms within a construction project (Azhar et al., 2009). Collaboration increases sustainability through information management (Interdonto, 2012). However the process of BIM data extraction could potentially be problematic as there are always considerable differences in subjective judgements between different supply chain actors (AlWaer et al., 2008), correlating with the problems with differing methodologies.

2.5 Barriers to sustainable construction

2.5.1 LCA boundaries, scope and subjectivism

The importance of understanding increases in carbon emissions from a behavioural perspective can be justified by the quantitative focus of CO_2 calculation. One of the main issues found in all lifecycle analysis research is the scope and boundary of the study. For example Asif et al., (2007) presented a lifecycle assessment of a dwelling home in Scotland, however the paper analyses the embodied energy of just five materials in detail in the building. Thus it cannot be seen as a full lifecycle analysis. The lifecycle of a building consists of a series of seven stages – raw material extraction, material processing, manufacturing, construction, use/occupancy, maintenance and end of life (Gustavsson and

Joelsson, 2010). Most studies have focused on the operational phase of a building alone due to concerns over energy consumption, which does not acknowledge any other lifecycle phase (Ortiz et al. 2009). The operational phase of a building accounts for around 50 % of energy use (Adalberth, 1999). The demolition phase just 1 % of energy use and the preconstruction phase could account for as little as 10 per cent (Kotaji at al., 2003). These cycles however have been widely discredited by Gustavsson and Joelsson (2010) who have suggested that the embodied phase could account for as much as 60 %, indicating the importance of full LCA using the cradle – cradle concept.

The shortcoming of these studies appears to be the complete exclusion of collaboration in the low carbon decision making process. Decisions are evident throughout the supply chain on every level and for every construction procedure for the purposes of quality and competitiveness (de Azavedo et al., 2013). When calculating CO_2 emissions, decisions are made on the scope and boundary of the calculation system based on product knowledge. If information is not available down the supply chain then vital emissions data may be excluded due to lack of availability. If the client requests a thorough emissions analysis, then data may be difficult to obtain. It has been maintained by several studies (Orlander, 2007; Ayuso et al. 2011; Bal et al., 2013) that most construction problems can be solved through effective collaboration and communication methods. By increasing collaboration and data sharing throughout the supply chain, those involved in the sustainability of construction projects are able to make better judgments on sustainable outcomes, particularly with increased data.

Despite an acknowledgment of behavioural processes in the sustainability effort, research is still focused in many ways on technology for the calculation of CO_2 (Abanda et al., 2013; Acquaye et al., 2008; Bilec et al., 2010). Emphasis on technology is not only evident in calculation systems, but also in the implementation of technologies in buildings which aim to reduce operational CO_2 outputs. The use of sustainable operational technology such as solar panels often requires high energy manufacturing processes. These processes intensify the embodied CO_2 impact throughout the supply chain (Fthenakis et al., 2008). A strategy for calculating embodied carbon requires greater collaboration as the calculation of embodied impacts requires data from third party sources. Embodied energy requires tracing direct and indirect energy inputs from the extraction of the raw materials, although boundaries need to be established (Dixit et al., 2010).

The calculation of embodied carbon has come to fruition in recent times with the implementation and success of zero energy buildings. These studies focus on operational energy or the 'use' phase of the building lifecycle (Marszal et al., 2011; Li et al., 2013a). The term zero energy building refers to energy efficiency in operation. Even zero energy buildings should take whole lifecycle impacts into account which would require increased data sharing (Hernandez and Kenny, 2010). In most cases however, the industry will opt for the traditional operational focus, often at the request of the client which is predominantly due to traditional construction methods and supply chain influences (Ahmed and Kangari, 1995).

As the client is often deemed to be the most important actor in the supply chain, it is the client who is considered to be the key innovator (Ahmed and Kangari, 1995; Cao, Li and Wang, 2014). If a client decides to take on a particular product or process then the rest of the supply chain follows in order to comply. Traditional and hierarchical structures can inhibit the innovation process if the client (at the top) refuses to use an innovation (Ip and Miller, 2012). Top down approaches in environmental issues are historically unsuccessful (Dirix et al., 2013; Diringer, 2011; Prins and Rayner, 2007; Victor 2009), and so the construction industry has been considered to perform poorly on environmental issues.

2.5.2 Construction and collaboration

One successful way to achieve sustainability is to engage stakeholders in all aspects of decision making (Reed, 2008). Stakeholder engagement enables construction companies to gain support for sustainable practices throughout the whole supply chain, shaping a firm's stance on sustainability (Persson and Orlnder, 2004; Bal et al., 2013; Ayuso et al., 2011). Communication flow amongst stakeholders throughout the supply chain is important in the development of sustainable practices (Jeffery, 2009). The flow of communication has an interesting link to the diffusion of innovation (Rogers, 1971). Rogers (1971) acknowledges the diffusion of innovation as a channel for communication where information passes between people and social groups. Innovation is not simply a new technology but a different way of working, which may be highly applicable to the construction sector.

With many different sections of the supply chain requiring active engagement in the decision making process (Jervis et al., 2014b), there is a growing body of knowledge suggesting that a set of guidelines will be important for the future of CO_2 calculation (Dixit, et al., 2012). Studies such as Pullen (1996) and Pears (1996) previously advocated such a guide in order to

make the decision making process for embodied energy much easier for industry workers. However, over a decade later there is still no such standardised industry guide and LCA systems are fraught with an array of assumptions and subjective system boundaries (Dixit, et al., 2012). The only noted movement towards a standard declaration system has been the establishment of Environmental Product Declarations (EPDs). These certificates deliver an environmental declaration for company products which outline environmental impact, although their uptake and success has been limited (Bovea, Ibáñez- forés and Agustí- Juan, 2014).

Carbon calculation relies upon subjective interpretation of information (Rajendran, 2001). Each individual will make their own scope and boundary decisions applicable to their specific project, causing subjectivity in carbon results. Even with increased knowledge and data, low carbon decision making can only be made through analysis of the data provided from each section of the supply chain. Data may not be uniform, and different standards and methodologies would most likely have been used to formulate carbon output calculations. If sustainability decisions are made from the beginning of the project and discussions and collaboration take place throughout, a standard calculation format can be decided upon, particularly as most discussions take place at the design stage of a project (Basbagill et al., 2013). The issues surrounding scope and boundary of carbon calculation have been supported in the literature (Chen et al., 2010; Dixit et al., 2013; Yang et al., 2013). If decisions can be made on these issues from the conception for the project by using technology based collaboration systems, low carbon decisions could be made much more easily.

2.5.3 Construction culture

Culture in the construction industry has been identified as one of the main problems for the lack of BIM uptake (RICS, 2013). It is thought that culture can significantly help or hinder the development of an industry by acting as a powerful force that has the ability to influence behaviour (Schein, 2006; von Meding et al., 2013). Culture is one of the last advantages that the construction industry and the companies working within it have to improve their competitiveness (Schein, 2006) as it supports value creation shaping company activities and procedures (Muratović, 2013). People inform the ways that developments are perceived and influence the way other stakeholders see projects (von Medling et al., 2013). The variances in culture between construction firms affect environmental attitudes towards all aspects of construction internally and externally (von Medling et al., 2013). In turn differences can

affect trade-offs which occur between stakeholders who are dependent on the ethical foundations of a culture of a company, indicating the potential power of cultural forces in sustainability development (Jones et al., 2007).

2.5.4 The nature of construction projects

One of the most challenging aspects for construction is the temporary nature of construction projects. Projects have a short life span that creates discontinuity in the development of construction knowledge and can be detrimental to knowledge transfer (Blayse and Manley, 2004). The nature of the construction process itself restrains the development of an 'organisational memory,' meaning that information is lost (Dubois and Gadde, 2002). Lost information hinders learning and so therefore in many cases the process of solving the same problem is reworked in each project (Barlow 2000). For the diffusion of innovation to be successful, a shared learning environment is required (Peansupap and Walker, 2005). LCA requires collaboration, communication and the effective diffusion of technology, all of which appear to have been hindered by poor relationship maintenance, particularly as the notions surrounding the diffusion of innovation are centred on effective communication and relationship influence (Rogers, 1971). The distribution of data and information regarding CO_2 outputs may be overcome through the diffusion of collaborative working processes as communicative networks increase (Rogers, 1971; Gatignon and Robertson, 1985). In addition to this, as more people accept an innovation and its success is viewed, uptake of that innovation generally increases as the perceived risk is reduced (Gatignon and Robertson, 1985).

2.5.5 Structural barriers in the construction supply chain

The main barriers which make it difficult to change the traditional ways of working in construction supply chain management are lack of management commitment, poor understanding, inappropriate structures and lack of commitment from construction partners (Akintoye et al., 2000). These key principle factors were most likely related to the culture of the industry and its resistance to change. Thus, education and proper orientation were considered key in construction supply chain management (Akintoye et al., 2000).

Bontekoe (1989) identifies ten possible barriers to logistics in construction which can be applied to supply chain management. These barriers included the need for extensive preparation for the required approval processes, the need for collaboration between public

bodies and finally conflicts of interest between businesses involved in a project (Bontekoe, 1989). The supply chain is not simply a system of the movement of products but also the flow of information, a highly important concept in CO_2 data sharing (Cartlidge, 2009) (see Figure 2.4). In construction supply chains, emphasis is placed on the client who ultimately has the greatest influence over the project and the supply chain (Kilinc, Ozturkb and Yitmen, 2015). Power can result in the disruption of relationship forming as the client has the ability to select any contractor and supplier regardless of the other supply chain actors (Ahmed and Kangari, 1995).

With the perceived communication issues with the current construction supply chain, interest has increased in the area of coordination and information flow improvements primarily for efficiency reasons (Zhang and Dhaliwal, 2009; O'brien et al., 2002; Vaidyanathan and Howell, 2007). Information is extremely important in sustainability through education and information sharing (Janda, 2011). The success of collaboration in a supply chain can be achieved by overcoming organisational boundaries through interdependence i.e. not acknowledging each process as individual but as a working strategy of symbiosis (O'brien et al., 2002; Love et al., 1999).

One of the main aims of effective construction supply chain management is the reduction of information delay along the chain, increasing the efficiency of the project and alleviating data duplication (Love et al., 1999). It is thought that as much as 30 % of construction cost is due to supply chain inadequacies including mistakes, delays and inadequate collaboration and communication flow (Kulkarni and Khutale, 2013). Highly efficient data flow can be useful for making low carbon decisions as people have access to data; lags in data availability can often lead to poor decisions (Heberling and Hopton, 2014). Software tools and improvement of business processes can be used separately or combined, but implementing software tools require changes to allow exchange of information between related parties (Vaidyanathan and Howell, 2007). The Industry Foundation Classes (IFC) data exchange standards (IAI, 1996) and Building Information Modelling (BIM) (Autodesk, 2002) are examples of currently available software and technology that offer the automated ability to exchange information. Their use however has not been widely accepted (Vaidyanathan and Howell, 2007).

2.5.6 Decision making in the construction industry

Being competitive and successful in the construction industry does not solely rely on cost (Rodriguez-Melo and Mansouri, 2011). Increasingly scholars are addressing the triple bottom line concept of economics, environment and societal impacts (Hart, 1995; Rodriguez-Melo and Mansouri, 2011; Florez et al., 2013). The triple bottom line encapsulates notions of strategy, ethics and technology into decision making, concepts which are also applicable to the concept of integrated working in construction management (Orlander, 2007; Minoja, 2012). Recent work continues to support the notion of achieving sustainability through lowering CO_2 emissions, requiring integration of the supply on a social and technological level (Janda, 2011). Rising CO_2 emissions are not simply a scientific issue but also a social issue. In many cases behavioural changes have a greater impact than any technical solution despite the academic focus on calculation and scientific resolutions to the problem (Adalberth, 1997; Thormacrk, 2002; Chang, et al., 2012). Scientific knowledge is of course required and technology will continue to be produced, however, thus far, CO_2 levels are continuing to rise in the industry despite these technological advancements.

The only noted drop in CO_2 emissions of 7% occurred between 2008 and 2010 which was directly in line with the decrease in construction owing to the economic downturn (Tansey, Spillane and Meng, 2014; Strategic Forum for Construction, 2010). CO_2 levels have in fact worsened as a smaller number of construction projects are essentially emitting the same level of CO_2, regardless of investment in technology. The acknowledgement of the investment in technology coupled with increasing emissions suggests the need to acknowledge behavioural LCA concepts. These concepts include addressing the impact of collaborative environments and supply chain perspectives on the construction emissions problem.

2.5.7 Low carbon innovation: Barriers to diffusion

Innovation is an important concept for any industry moving towards a potential period of change (Miller and Friesen, 1984). When new problems need to be solved then innovations must occur. Once an innovative concept is conceived it is then essential for it to achieve widespread use (Rogers, 1971). Encouraging construction companies to adopt low carbon strategies for buildings will require innovative processes, however the success of these innovations will rest on their ability to spread or diffuse throughout an industry, encouraging widespread adoption (Rogers, 1971).

A challenge affecting the diffusion of an innovation is similarity of products (Gatignon and Robertson, 1985).Evidence of this is widespread in emissions measurement systems with the similarity of LCA products. If the product is not already diffused it will ultimately require a strong product to break the pattern of acquisition. If a product is launched into a saturated market, then the innovation must be clearly positioned as 'different.' In this sense, the launch of a new method of low carbon decision making using supply chain relationships and collaboration would be novel (Hill, 1970).

The similarity of products acting as a barrier to sustainability (Gatignon and Robertson, 1985) is particularly applicable to CO_2 lifecycle analysis tools and products. There are a vast array of competing products such as Elodie (Chevalier et al., 2009) Lifecycle Explorer (Hischier, 2011), EcoInvent (Frischknecht and Rebitzer, 2005), Athena Eco calculator (Singh et al., 2011), Envest, Green guide, IMPACT, Environmental Profiles Methodology (BRE, 2014) BEES (Norris and Yost, 2001) and Simapro (Ip and Miller, 2012) to name a very small selection. Arguments for market saturation could be strongly supported. Many of the products are competing for the same section of the market with varying degrees of success. Therefore it is unsurprising that the diffusion of this technology has been relatively slow. The similarity of these products with no single product offering anything different or outstanding has clearly inhibited the diffusion process (Gatignon and Robertson, 1985).

It has also been argued that the traditional construction procurement system is also an innovation inhibitor (Kumaraswamy and Dulaimi, 2001). Traditional procurement discourages innovation as a premium is put on speed, quality and price (Blayse and Manley, 2004: Abanda et al. 2013). There are distinct procurement roles put in place and significant self-protection which occurs due to fears of losing contracts (Kumaraswamy and Dulaimi, 2001). Further risk of failure through the implementation of innovative systems is a concept that clients may not be comfortable with. As a counter argument Walker et al. (2003) suggested that much higher levels of innovation occur when a more innovative method of procurement is used in the form of an integrated team. Integration is difficult to achieve as historically people will always try to resist change due to social and cultural barriers (Peansupap and Walker, 2005; Abbott, 1988; Rogers, 1971).

An additional and interesting effect of the sheer volume of technology is the differences in methodological approaches used in each tool; heavily supported by the scientific literature. One of the most noteworthy problems associated with embodied energy calculations stems

from differing methodological approaches. Dixit et al. (2012) concluded that these inconsistencies in methodologies mean that there is irregularity across all buildings and ultimately complete incomparability. On this level, data sharing would require full collaboration from the outset of a project. A summary of the sustainability barriers in the construction industry is shown in table 2.2.

Table 2.2 Summary of sustainable construction barriers

Barrier	Description summary	Reference
LCA boundaries, scope and subjectivism	The scope and boundary regarding CO_2 data analysis is subjective. Boundaries used by one researcher or company may not match those of another. Different techniques and technologies and the subjective nature of inclusion and exclusion criteria create challenges in effective monitoring of CO_2 emissions. In addition to this there is a significant gap in this research relating to the concept and inclusion of collaboration techniques in low carbon decision making.	(Asif, et al., 2007; Ortiz, et al., 2009; de (de Azevedo, et al., 2013)
Construction and collaboration	The literature suggests that sustainability can often be achieved through higher levels of collaboration throughout the supply chain. Communication flow aids data and information sharing and understanding which can ease the low carbon decision making process. There is a lack of collaboration regarding sustainability within the construction industry which provides challenges for the ease of low carbon decision making processes. The lack of collaboration makes the process of deciding on scope and boundaries in the carbon calculation process challenging.	(Persson and Orlander, 2004; Jeffrey, 2009)
Construction culture	The culture of a company informs its behaviour. The construction industry is engrained in traditional working strategies, which are often devoid of environmental consideration. Emphasis often remains on time, cost and quality. Change is difficult to achieve in ingrained working cultures, therefore it can often become a barrier when new ideas, innovations or working strategies are suggested.	(Schein, 2006; von Meding, et al., 2013;
Structural barriers in the construction supply chain structures and decision making in the construction industry	The linear construction supply chain structure potentially causes widespread problems for management, commitment, collaboration, and low carbon decision making. The structure inhibits information flow, data exchange and efficiency. Lack of data flow and exchange does not enable the exploration of sustainability issues during a project. Therefore low carbon decision making is problematic as the facts are not available to share effectively. Decisions in the construction industry are formulated around cost in most cases. There has in recent times been movement towards encapsulating the triple bottom line approach into the construction network, incorporating social considerations in to decision making. The decision making structure in linear in format and so this often makes communication between parties	(Akintoye, et al., 2000; Obrien, et al., 2002; Janda, 2011; Rodriguez-Melo and Mansouri, 2011; Hart, 1995; Janda, 2011)

Barrier	Description summary	Reference
	difficult and so therefore decisions are often challenging to make with a lack of information.	
Low carbon innovation: Barriers to diffusion	The diffusion of innovation is seen as a significant sustainability enabler; however there are several aspects of the construction industry which inhibit the development of sustainability. These include the similarity of LCA products, traditional procurement systems and social and cultural construction barriers.	(Gatignon and Robertson, 1985; Kumaraswamy and Dulaimi, 2001; Peansupap and Walker, 2005)

2.6 Sustainability enablers in the construction industry

Having discussed the barriers which inhibit the development of low carbon decision making in the construction industry, it is also important to discuss sustainability enablers. These are concepts found in the literature which could theoretically aid the development of low carbon decision making in the construction industry. The following section will address the concept of innovation and how it could improve construction sustainability, how innovation is facilitated, influential relationships and collaboration.

2.6.1 Innovation in the construction industry

In order for change to occur there is a need for innovation, this can be an innovation in practice, work strategy or technological innovation (Rogers, 1971; Brown, 1981). It has been argued that construction itself is not conducive to being innovative (Miozzo and Dewick, 2004; Pries and Janszen, 1995), primarily because buildings themselves are expected to be highly durable. Therefore construction companies will always use tried and tested techniques to reduce risk (Blayse and Manley, 2004). An increasing number of studies argue that successful innovation requires a culture of innovation (Panuwatwanich, et al., 2008). Innovative firms almost always have a high level of freedom coupled with risk tolerance (Martins and Terblanche, 2003; Steele and Murray, 2004). Freedom and risk tolerance are generally not common attributes of the construction industry which is both high risk and traditional (Abderisak and Lindahl, 2015). Therefore it is not surprising that it lacks innovative processes in low carbon decision making.

Slaughter (2000) however has argued that innovation in the construction industry does occur and can take many forms. These forms are referred to as incremental, radical, modular, architectural and system innovation.

- An incremental innovation is a small innovation based on existing knowledge.
- A radical innovation is an innovation based on breakthrough science or technology.
- A modular innovation is a change in concept with for example a particular component (Slaughter, 2000).
- An architectural innovation is linked to other components or systems.
- A system change comprises of multiple and integrated systems of innovations (Blayse and Manley (2004).

Slaughter's (2000) versions of innovation types provide further expansion on those put forward by Freeman (1974) with the introduction of 'incremental,' 'radical' and 'revolutionary' innovation types. A revolutionary innovation is considered to be the most extreme of the three, likely to cause significant economic change (Freeman's, 1974). Male and Stocks (1991) have argued that many of the innovation types are primarily redundant in construction. In the majority of cases only incremental innovations are generally seen or used. The implementation of the Computer-aided Design (CAD) drawing system counteracts this claim as the new drawing systems revolutionised the architectural drawing process (Kale and Arditi, 2010). Extreme types of innovation are problematic as it is difficult to maintain employee involvement if management systems are not embracing new innovations and supporting staff to use them (Panuwatwanich et al., 2008).

Innovation in the construction industry encompasses a wide range of stakeholders which Marceau et al. (1999) referred to as a 'product system.' In this product system there are many participants including governments, contractors, specialists, suppliers, architects, certification bodies and the workforce. It is an interdependence of organisations providing a matrix of inter-sectoral patterns of innovation flows (Blayse and Manley, 2004; Arditi et al., 1997; Schmookler, 1966). The economic input output methodology for carbon calculation is reminiscent of this process, working on sectoral economic flows for understanding industry relationships (Chang, et al., 2012). These industry relationships could be pivotal in the future of carbon calculation via a holistic LCA method, as supply chain collaboration aids decision making (Love et al., 1999). Sectoral relationships could aid the understanding of where communications on carbon calculation need to occur. The I-O model could theoretically aid this process by highlighting sectoral economic flows (Alcorn and Baird, 1996; Pullen, 1996; Fay and Treloar, 1988; Ding, 2005).

2.6.2 Facilitators of innovation

Thus far it has become clear that innovation is required in order to lower CO_2 emissions, not simply innovation in terms of technology but also innovation in work strategies. Innovation is likely to be essential for lowering emissions in the construction industry as any industry change will require the implementation of novel concepts. It is therefore essential to understand how this innovation may occur.

Rogers (1971) and later Johnson et al., (2008) have stated that innovation is not simply seen as an invention but also the conversion and attainment of the knowledge required in order to make an invention work. There is a strong sense in the literature that the concept of innovation will lead to competitive advantage regardless of the industry (Frambach, 1993; Hussain and Ilyas, 2011; Tidd, Bessant and Pavitt, 2005). Studies have argued that low cost business strategies are often not enough for a successful business (Songip et al., 2013). Ling (2003) has furthered these arguments by suggesting that innovation is becoming a fourth dimension of competitiveness in the construction industry, alongside the traditional cost, quality and time (Abanda et al., 2013; Monghasemi et al., 2015). There is a sense of disregard about the benefits of sustainability with regard to long term running costs as emphasis remains on capital finance (Wang, Chang and Nunn, 2010; Feminias, Kadefors and Eden, 2009). History has shown by the volume of life cycle analysis products available that invention alone is not enough for sustainable construction innovation.

It is ultimately the way in which technologies or advancements in working strategy diffuse through the industry which is most important (Songip, et al., 2013). Even the most significant technology must be diffused in order for it to be economically viable. The diffusion pace of technology is the most important aspect of innovation for economic gain (Hall and Khan, 2003). In order for any CO_2 technology to be viable in any industry it must produce income. In the construction industry innovation is generally considered to be notoriously low; however it is being encouraged (Songip et al., 2013). Although the core concept of diffusion theory is not purely technological (Rogers, 1971), construction innovation has historically been driven by new technologies. A gap in the research has emerged for movement away from a technology driven focus towards behavioural approaches to LCA, creating novel insights into emissions analysis (Jervis et al., 2014a).

In order to successfully integrate an innovation into the industry it is essential to understand the innovation driver. The notion of innovation being driven by technological advancement is

known as ‘technology push’ (Rothwell, 1992). Based on Schumpeter’s philosophies, the technology push concept provides a view of a company which will allow scientists to create new knowledge. A technological innovation must then be rolled out to the rest of the organisation in order for it to be marketed and distributed (Johnson et al., 2008). The technological advancement acts as a push in order to understand what goes into the market place.

The second view of innovation is known as ‘market pull’ this view does not only consider the innovation itself but also its use which is exceptionally important in the diffusion of LCA products. It is essential that there is a market for a product before it is released and it is even more important to understand the way in which users will potentially interact with it (Johnson, et al., 2008). The market pull model of innovation has been heavily alluded to since Eric Von Hippel’s work on the importance of innovation users. Others such as Arditi et al. (1997), have suggested that the market pull ideas are based on Schmooker’s (1996) concept that innovation is driven by a firms perception and drive for increased profits. If innovation is not considered instantly profitable then it will not be used (Hu and He, 2014). The ‘user’ elements of the system design are largely unimportant (Arditi et al. 1997).

However von Hippel (1976) makes a compelling case for the continued emphasis on user importance. 80% of cases analysed in his study highlighted that the user is in fact the key innovator and the producer is simply the provider of materials. In terms of a construction supply chain the user is often seen as the client who has the most power. Therefore in theory if there is greater client demand then this would increase the uptake of products and processes which could aid low carbon decision making. It is argued that ‘lead users’ hold the most weight in the spread and uptake of technology and innovation however this can be problematic. It makes companies vulnerable to disruptive markets and also makes it difficult for them to identify niche markets which in some cases can be more economically beneficial (Johnson et al., 2008). Alternatively companies within similar social networks in the past have pursued technologies without any basis for success in the quest to remain acknowledged as a legitimate player (Barreto and Baden-Fuller, 2006; DiMaggio and Powell, 1983).

2.6.3 Influential relationships

At its core the construction industry is built on relationships and influence (Dubois and Gadde, 2000). These relationships can have a significant impact on changes and innovations

within the industry (Dubois and Gadde, 2002; Miozzo and Dewick, 2002). These relationships are absolutely essential for information flows between individuals in the supply chain. One of the most interesting references highlighting the nature of these relationships was alluded to by Dubois and Gadde (2002). They used the term of 'loose couplings' to describe industry relationships that was highly descriptive of the temporary nature of relationships in construction. These types of relationships can both encourage and discourage innovation. It encourages in the sense that every project can be experimental. However, it can be also discourage innovation because each project changes and it becomes more difficult to retain structures, knowledge and relationships when they are no longer required (Songip et al., 2013; Blayse and Manley, 2004).

2.6.4 Increasing collaborative communication

In order for CO_2 data to be shared accurately, discussions must initially take place regarding the methodology used, to ensure uniform calculations. In most cases a firm will use their own methodology which could be different to all other methods used in the supply chain. Using firm centric approaches to LCA can have limiting consequences for the future sustainability of the construction industry, as emissions from buildings are essentially incomparable (Atkinson et al., 1996; Davies, 2001; Thormark, 2006; Pullen, 1996; Fernandez, 2006). A construction company can choose their own model which is suitable to meet their calculation needs. Whereas one model may calculate extremely low CO_2 emissions, another model may produce much higher readings for the same building. In addition, there are added concerns surrounding the standards used to complete the analysis. For example UK standards such as PAS-2050 (2011) can provide a different output to international standards (ISO-14040[4], 2006). Consequently CO_2 emissions from a range of different buildings become incomparable; therefore there is no level of CO_2 that a company can aim for. It is because of this that a varied number of studies have suggested that embodied energy results have deep variations due to different sources of information from around the globe; a noteworthy data uncertainty issue (Buchanan and Honey, 1994; Crawford and Treloar, 2005; Ding, 2005; Nässén et al., 2007; Dixit et al., 2010). Problems are not limited to standards but also the sheer number of data sources that could be selected by the analyst, making the results completely subjective (Junnila and Horvath, 2003).

[4] Environmental management & Life cycle assessment – international standards (ISO-14040, 2006)

Despite the inconsistencies and flaws in embodied CO_2 data assessments the process itself is relatively straight forward to analyse. A great deal of precision on outputs can be achieved with phases such as embodied, operational, consumption and global warming potential when analysed singularly. However the total lifecycle CO_2 emissions of a building are exceptionally difficult to measure (Barnthouse, 1998). Despite academic acknowledgment and recognition as an important aspect to the development of sustainable buildings, there is still no widely accepted method of total lifecycle CO_2 measurement. The result is significant and wide ranging inconsistencies and variability found within LCA models and databases (Dixit, et al., 2010; Crowther, 1999; Harris, 1999; Lenzen, 2000; Ding, 2005).

Finally, a further reason which could be attributed to the low uptake of these products has also been put forward by Gatignon and Robertson (1985). In Gatignon and Robertson's (1985) study the authors argue that if an innovation does not fit within understood and existing consumption systems, the uptake of an innovation could be problematic. It would require the company to move away from existing systems and adopt new ones which is often met with opposition. Ling (2003) has also argued that technologies must be understood within their market contexts in order to be successful. If the new innovation is a technology, it is exceptionally important for that technology to be compatible with the industry, thus reducing the potential for failure by increasing ease of use (Songip, et al., 2013). As a traditional industry construction companies are not comfortable with adopting new products and systems which force them to work outside their traditional activities or increase business risk (Dimoudi and Tompa, 2008; Blengini and Di Carlo, 2010). A summary of the sustainability enablers can be seen in Table 2.3.

Table 2.3 Summary of sustainability enablers in the construction industry

Enabler	Description	Reference
Innovation in the construction industry	The construction industry is not considered to be an innovative industry due to the nature of buildings. Tried and tested techniques are considered best to reduce risk and increase durability. It has been argued that innovative cultures are required for innovative processes to take place. If cultural behaviour could take on an innovative guise then innovation in the development of low carbon decision making can occur. Male and Stocks (1991) have argued that small incremental innovations are only relevant in construction, however behavioural changes towards innovation could encourage greater success.	(Pries and Janszen, 1995; Blayse and Manley, 2004; Male and Stocks, 1991; Slaughter, 2000; Panuwatwanich, et al., 2008)

Enabler	Description	Reference
Facilitators of innovation	Innovation does not require extreme technological advancement, small changes in working strategies can also achieve positive results, particularly in the area of low carbon decision making. Some have argued that innovation is fast becoming a necessity in construction in order to achieve a competitive advantage. The diffusion of a product or work strategy is necessary for a product or process innovation to be successful – technology push. The market must also be there for the new concept to be positioned. These facilitators are evidenced in the industry and could provide positive advancements towards the adoption of greater low carbon decision making processes.	(Rogers, 1971; Johnson, et al., 2008; Frambach, 1993; Rothwell, 1992; Schmookler, 1996)
Influential relationships	Influential relationships can have a significant impact on the diffusion of new concepts within an industry. Although some have argued that the nature of construction can discourage these relationships, there is significant evidence of their occurrence. Ultimately, if one company sees the success of another, this can influence their decisions regarding whether or not to take up a particular product or process.	(Dubois and Gadde, 2002; Blayse and Manley, 2004; Songip, et al., 2013)
Increasing collaborative communication	Increasing communications enables greater collaboration and data sharing to take place. One of the key issues found in construction LCA is the sheer number of products and processes used, inhibiting the development of a universal acknowledgement of low carbon decision making in construction. Increasing communication could improve awareness and enable others to understand or decide upon the best methods to use. It is also in many cases necessary to trace CO_2 throughout the supply chain in order for accurate calculation results. If people do not communicate then this task becomes an impossibility.	(Pullen, 1996; Fernandez, 2006; Dixit, et al., 2010; Jervis et al., 2016)

2.7 Overcoming barriers: Lifecycle thinking – a holistic approach to LCA

The vast array of available LCA software and the issue of increasing emissions levels have provided an impetus for studies to move towards a more holistic approach to LCA. Such an approach could be termed 'lifecycle thinking'; the notion of which is that the implications of decision making directly affect CO_2 outputs throughout the supply chain. Lifecycle thinking looks at LCA from the perspective that technological assessment alone is insufficient, thus providing a rounded view of the importance of corporate social responsibility (CSR) throughout the supply chain (Heiskanen, 2002; Löfgren et al. 2011).

There is a distinct lack of significant literature dealing with the merging of building and management science, particularly when assessing CO_2 emissions. The assessment of the construction supply chain, LCA technology and behavioural implications of sustainability have shown that the key failing in widely used low carbon decision making systems is found

in information sharing and collaboration (Pullen, 1996; Fernandez, 2006; Dixit et al., 2010). Problems with collaboration could be assessed through analysis of construction supply chain information flows. A change in the way the construction industry works could be induced by using new working strategies implemented through behavioural change. Behavioural change is thought to be critical in achieving a sustainable future in the construction industry (McKenzie- Mohr, 2000; Janda, 2011). Behavioural change could be accomplished through knowledge acquisition and retention, however, McKenzie-Mohr (2000) has also argued that enhanced information levels do not always encourage long term behavioural change; reminiscent of the arguments provided by Geller, (1981) and Finger (1994) who have argued that enhancing knowledge about sustainability is not always enough for effective action to take place.

It is worth noting that in many cases increased information (as evidenced by governmental campaigns) for issues such as energy efficiency have resulted in poor behavioural change rates in the long term, even if the changes are economically positive (Owens and Driffill, 2008). Regardless of constructive outcomes people tend to follow habitual ways of working even if they are economically and environmentally detrimental (Stern and Aronson, 1984; Costanzo, et al., 1986; Mckenzie-Mohr, 2000). In almost all cases a short term change is noted, followed by continued traditional ways of working, applicable to the way in which construction companies behave regarding environmental issues. Despite potential economic and environmental benefits, traditional ways of working are still seen as being much more effective both in terms of finance and efficiency as the industry resists change (Peansupap and Walker, 2005). Due to these experiences Stern and Aronson (1984) have claimed that behaviour is ultimately shaped by complex cultural and social interactions. These are most likely maintained in construction by those traditional values which cannot be overcome by technology alone, as interaction essentially forms every aspect of the LCA process. The concept of using these social interactions in an advantageous way could improve CO_2 data collection throughout the construction supply chain. Calculation data can be shared more freely in a way which encompasses all those involved in a project at each supply chain stage. In order to assess how these interactions could aid decision making, it is important to assess the construction supply chain itself and potential avenues for change.

2.8 Examining the phenomenon of LCA in the construction industry through a theoretical lens

The key issues found in the literature regarding CO_2 LCA have been centred on both technological and social problems, including supply chain impacts. There is a need to understand why CO_2 emissions are continuing to increase in the industry. There is also need to understand why it is so difficult for those in the supply chain to make low carbon decisions with the vast array of available technology, which has not been taken up widely in the industry. One way of understanding this phenomena is through the lens of (Rogers, 1971) diffusion theory and DiMaggio and Powell's (1983) institutional theory. These two theories have been selected because they can be used to provide an understanding of how institutional pressures impact on the diffusion of low carbon innovation in the construction industry.

The diffusion theory lens helps to understand how new technologies and work systems are taken up throughout the supply chain. Diffusion theory supports the notion of increasing and opening up communication channels within an industry, thus 'diffusing' innovative methods of working throughout a business (Rogers 1971). Using this concept will enable a greater understanding of the facilitation of carbon data throughout a construction supply chain. Diffusion theory can enable an understanding of how increased communication and key innovators can encourage the uptake of a new system or process. DiMaggio and Powell's (1983) institutional theory explains how firms respond when subjected to mimetic, normative and coercive institutional pressures. The application of institutional pressures will aid the understanding of how pressure exerted on businesses internally or externally will affect the adoption of new business strategies or products.

2.8.1 The diffusion of innovations

As part of this research Rogers (1971) diffusion of innovation theory was used as a way to examine how innovation is conceived and diffused throughout an industry in order to achieve widespread adoption. It aids the understanding of how technological and methodological innovation integrates and moves successfully through construction industry supply chains. The construction industry is unique in the way it operates with short term contracts, location specificity, high risk and high costs (Hampson and Tatum, 1997). Short lived construction relationships ultimately affect information sharing and retention (Songip et al., 2013). These

relationships affect the way in which innovations diffuse and present themselves in the industry and may provide reasoning behind the lack of widespread LCA use.

The main issue with the contract length of construction projects is that collaboration does not have time to mature, meaning that innovation will be slow to move through the industry. Higher levels of innovation in the construction industry would increase the possibility of its contribution to economic growth (Blayse and Manley, 2004). Investment in innovation in construction is notoriously low. There is also a significant gap between industry and academic research that has been problematic for the introduction of CO_2 technologies and their eventual uptake (Dulaimi et al., 2002).

In addition to the complexities of short term relationships, the construction supply chain structure is also problematic for the diffusion of innovation (Cheng et al., 2001). The structure inhibits the development of communicative relationships as those in the supply chain fulfil their individual roles, disregarding other supply chain inputs (Kornelius and Wamelink, 1998). The most useful aspect combining diffusion theory and institutional theory is the combined perspective they can provide. Institutional theory can aid the understanding of how institutional pressures impact the diffusion of innovation. This notion could be applied to the construction industry as it is deemed as an institutionalised industry which historically struggles to implement innovation (Forster et al., 2015).

2.8.2 Roger's (1971) and Brown's (1981) core diffusion theories

Much of the literature surrounding diffusion theory has been based on Rogers (1971). Rogers argues that diffusion is not solely driven by invention or the innovation itself but also the flow of collaborative processes. There is strong avocation of influential relationships and the way in which they impact on the diffusion of innovation, more so than in other studies such as Brown, (1981). Its application to the construction supply chain is highly relevant for the following reasons; firstly it focuses on collaborative pathways of influence which are seemingly lacking in the fragmented construction supply chain (Korneleus and Wamelink, 1998; Cheng, et al. 2001).

Secondly its assumption of a linear decision making process replicates the top down approach to decision making within construction. It is highly applicable to the construction supply chain as decisions are often made in a linear format due to the hierarchical structure (Rosinski et al., 2014; Dirix et al., 2013). The assumption of a linear decision making process

has come under criticism. They have been deemed unrealistic as various decision making processes can often overlap or be repetitive (Winch, 1998; Songip, et al., 2013); however the linear format of the chains assumes linear decision making processes. Furthermore any additional external influence on the decision making process can be addressed by using institutional theory in this research.

Finally the consumer driven approach of Roger's diffusion theory is also highly applicable to this research. As the client appears to be the most important actor in the chain they assume the role of the consumer and so therefore it could be argued that construction is a consumer driven industry. Although Roger's (1971) theory of diffusion appears to provide the most promising theoretical lens for this research it is also important to provide further critical assessment of its application in order to justify its use.

The main criticism of Roger's diffusion theory is that it is too focused on the demand side of innovation (Brown, 1981). There appears to be much less of an acknowledgement of innovation developers so therefore the supply angle of diffusion has to some extent been ignored; highlighting a deficiency in the theory (Songip et al., 2013). However, in line with the client providing the demand from a significant position of power, this does not appear to be a problem for Rogers (1971) theory use. Since Rogers' (1971), other studies such as Hall and Kahn, (2003) have argued that adopters cannot simply be categorised into groups in order to explain adoption behaviour. There will be a range of external factors which will in essence have an effect on the ultimate outcome. An admission such as this provides reasoning for the use of institutional theory alongside diffusion theory to identify these factors whilst addressing the adopter category correlations alongside construction supply chain actors.

Brown (1981) has iterated that a criticism of Roger's (1971) theory is that it is only applicable to consumer innovation rather than technological innovation. As previously alluded to however, the application of a consumer driven theory could be effective at explaining the adoption process due to client power and hierarchical approaches (Rosinski et al., 2014; Ryd, 2014; Ryd, 2004) which place the client in the consumer position. By using Roger's (1971) diffusion theory the diffusion of innovation from the perspective of new working strategies and decision making processes can be analysed, rather than a purely technological perspective of innovation diffusion; although it is important to assess technology adoption due to the perceived failures of technological LCA processes.

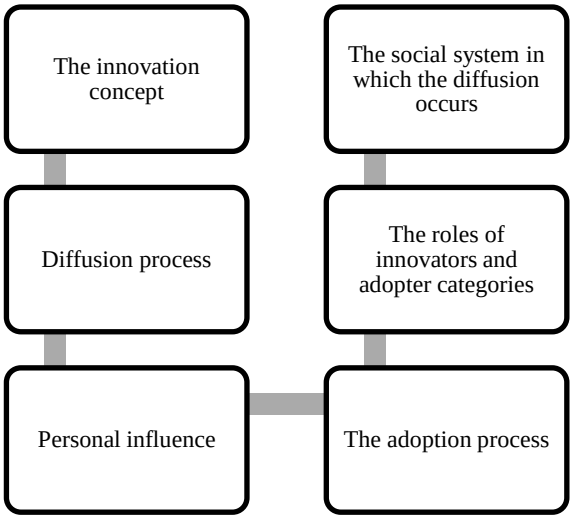
Brown (1981) focuses on technological innovation diffusion addressing the way in which the user adopts the innovation (Brown, 1981). Therefore the use phase of innovation is a critical component of Brown's diffusion theory which is more applicable to the integration of a life cycle analysis technology or product rather than a collaborative process (von Hippel, 1976). Innovation must lead to profitability and will almost always be determined by the nature of previous technological advancement (Songip, et al., 2013). Continuation of similar strategies and pathways correlates well with the notion of DiMaggio and Powell's (1983) version of institutional theory. Those seeking to remain legitimate act within perceived social norms, or compete at the level of their social peers (DiMaggio and Powell, 1985). The phenomenon is particularly relevant in construction as new technologies and working strategies are approached with caution in high risk construction environments. Tried and tested methods are always the preferred option particularly in design build contracts (Blayse and Manley, 2004; Xia et al., 2013).

2.8.3 The diffusion process

In order to understand how a new system or technology may carry through an industry it is important to understand how the diffusion process works. Diffusion theory is not only associated with the flow of invention and innovation but the flow of communication (Gatignon and Robertson, 1985; Rogers, 1971). Diffusion is not simply about spreading products, but theories, practices and services. It requires an understanding of the impact that personal relationships and influence within an organisation have on the adoption of products and processes. Diffusion itself has been referred to as a type of social change, indicating the importance of behavioural understanding. Adoption of an innovation will in most cases have social consequences (Rogers, 1971). The notion of social consequence is highly applicable to the normative, coercive and mimetic pressures found in institutional theory. Internal and external change has an impact the adoption of new procedure (DiMaggio and Powell, 1983).

The foundations of the diffusion process are shown in Figure 2.7 below, noting the importance of social networks; communication and personal influence (Rogers 1971).

Figure 2.7 Rogers (1971) diffusion theory foundations



(Source: Gatignon and Robertson, 1985)

Diffusion will always occur within the boundaries of a social network or market section (Rogers, 1971; Gatignon and Robertson, 1985; Gouwes and Reed van Oudtshoorn, 2011). The extent to which any idea or innovation is accepted within this network will depend on the interactions between individual members (Littlejohn and Foss, 2008). Social leaning in diffusion highlights the potential for integrated approaches to information sharing in construction, not least to encourage others to adopt products via information retention. The set of complex interactions in the supply chain can heavily impact the diffusion of any new idea or technology (Bass, 2004). In close proximity homogenous groups are more effective at transferring ideas (Gatignon and Robertson, 1985). Cultural norms however have also been found to act as a barrier to the diffusion of innovation as violation of the cultural system in an organisation may result in sanctions (Koester and Lustig, 2012).

Diffusion will occur at the social network level between similar businesses and peers (Gatignon and Robertson, 1985). These decisions are made based on personal perceptions of innovation characteristics or competitive advantage (Heany, 1983). Behavioural implications, interaction and personal influence are highly important in the diffusion process (Bass, 2004). The notion of influence is extremely important in a business network as it transcends through peers who have similar personal characteristics. The practice of ideas filtering between similar networks is often referred to as homophilous influence (Gatignon and Robertson, 1985). Homophilous influences could mean that an innovation could spread quickly simply because the business network holds similar beliefs. External influences are often referred to

as hetrophilous influences (Gatignon and Robertson, 1985). These influences have the greatest impact as their reach within an industry is much wider. It is argued that opening up communication throughout the supply chain increases the chance of external influences having an impact, even if communication ties are weak (Granovetter, 1973). Weak ties between groups have the potential to explore previously unobtainable avenues of business whilst simultaneously encouraging new ideas by transcending normative barriers (Gatignon and Robertson, 1985). Consequently, influencing external groups could mean that innovations have greater potential to spread beyond the boundary of one business through an entire industry.

The innovation process is deemed to be relatively expensive and in order for a company to innovate it is essential that they are aware to some extent about how far and at what speed a product can penetrate the market (Gouws and Rheede van Oudtshoorn, 2011). The pace of diffusion can be assessed by using a diffusion curve (Rogers, 1971). The pace of diffusion is not a steady process and can be categorised into several common steps using the 'S' curve. An innovation will go through an initial process of slow adoption followed by rapid expansion before a plateau occurs. At this point demand has reached its peak (Gouws and Rheede van Oudtshoorn, 2011; Rogers, 1971; Johnson et al., 2008). The height of the 'S' curve demonstrates the extent of diffusion whereas the shape highlights the speed. Figure 2.8 shows a typical diffusion 'S' curve.

Figure 2.8 Roger's (1971) diffusion of innovations curve

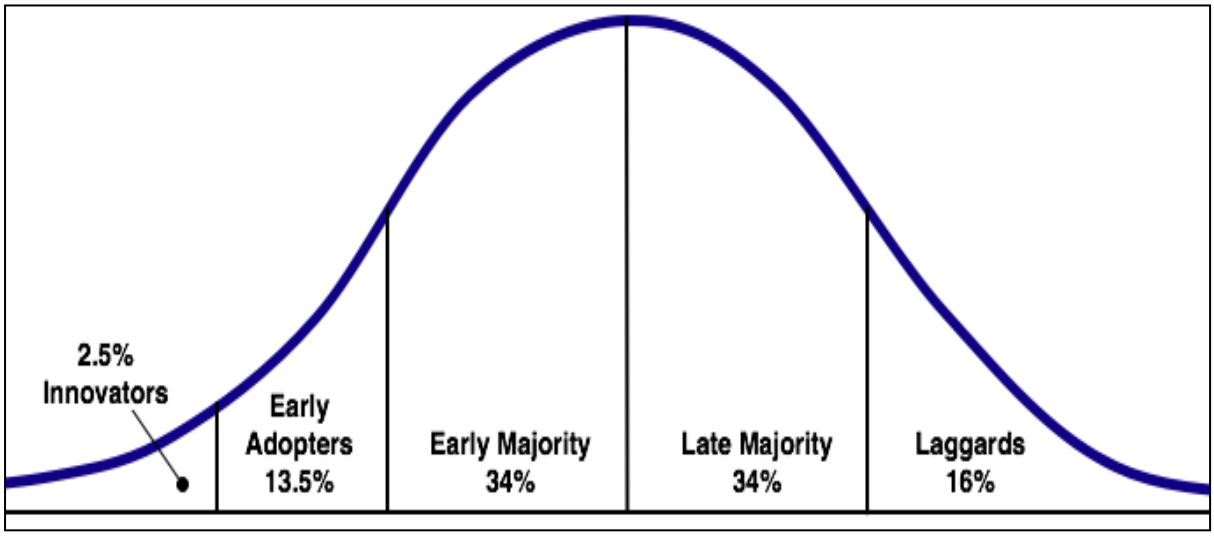
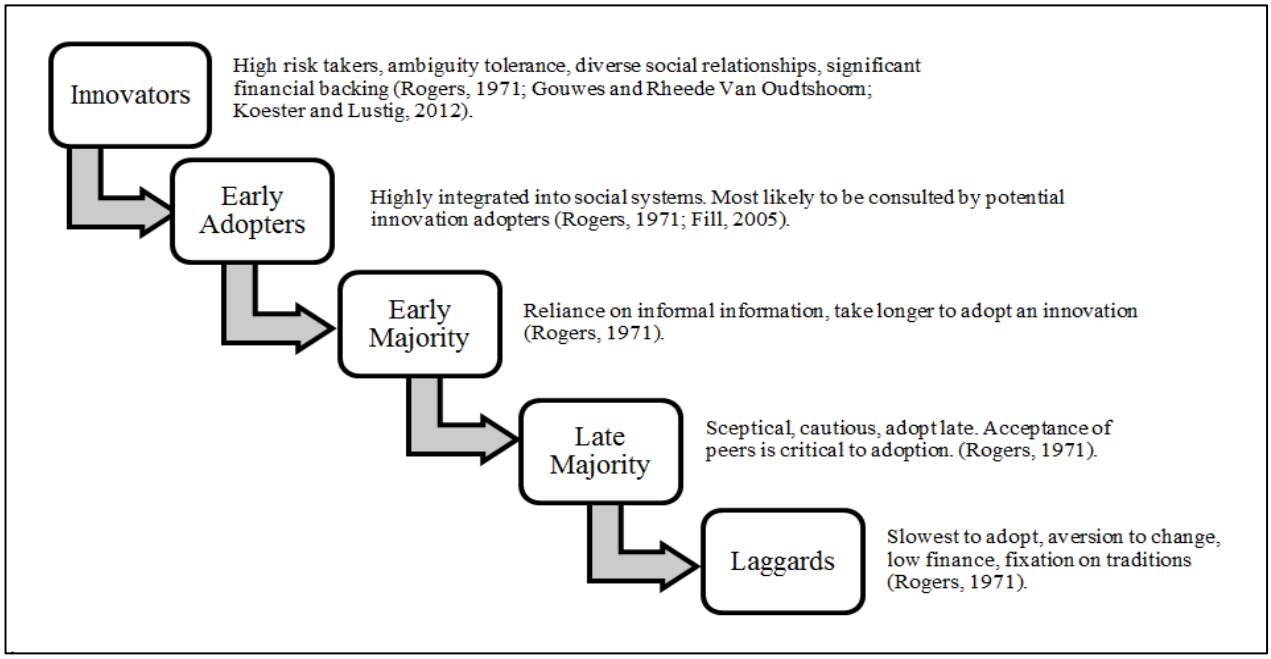


Image sourced online available at http://rickwilsondmd.typepad.com/rick_wilson_dmds_blog/2010/03/the-rogers-diffusion-of-innovation-curve.html

Figure 2.8 illustrates a range of different adopters which are vital to the diffusion process. These include innovators, early adopters, early majority and late majority. Each adopter is described in Figure 2.9.

Figure 2.9 Adopter categories explained



During the early stages of diffusion the rate of individual adoption is low (Rogers, 1971; Johnson et al., 2008). The rate accelerates slowly until enough people are using an innovation or product to create the perception of popularity. At this point others believe or perceive that they are 'missing out' and so greater adoption will occur. It is also the point at which mimetic isomorphism occurs. The threat of being left behind becomes apparent and the fear of losing legitimacy presents itself (Mahler and Rogers, 1999). The imitation factor is thought to be vital for successful diffusion; something which can occur more quickly with collaborative systems which are governed by close proximity working strategies (Markus, 1987).

The success of an innovation for one company will encourage others to want to replicate it. The innovation leaders are essential to diffusion theory. In the case of the construction industry the leader of the innovation is highly likely to be the client who is deemed as the key innovator in the chain, often held in place by normative and coercive pressures (Cao, Li and Wang, 2014; Ahmed and Kangari, 1995; Hartman et al., 2008). In the diffusion process innovation will continue to be adopted until a 'critical mass' is reached (Rogers, 1971). Mahler and Rogers (1999) define this mass as the point at which an innovation has enough

adopters to sustain itself. Decisions in the diffusion process are not considered to be collective and so therefore each individual within the system will make his or her own adoption decisions (Rogers, 1971; Gouws and Rheede van Oudtshoorn, 2011). These decisions are governed by what is viewed as a legitimate or successful working practice, informing the importance of observing others achievements. Evidence found in Toole (1998) has shown that firms who are much more willing to take on non-diffused products are those firms who significantly reduce the risk by obtaining information regarding that innovation. The application of diffusion theory to this research could be beneficial as it advocates the importance of collaboration, a concept considered as an essential part of successful construction (Cheng et al., 2001; Love et al., 2004).

2.9 DiMaggio and Powell's (1983) institutional theory: Coercive, normative and mimetic isomorphic pressures

The grounding for institutional theory can be traced back to the 1950s where theorists analysed changes in organisational structures. In 1957 a contribution was made by Selznick to identify factors that motivate organisations to make changes. The theory explains how the institutional environment influences the legitimacy[5] of an organisation (Prue and Devine, 2012). Beliefs and processes all contribute to the values of an organisation (Oliver, 1992). The theory acknowledges that institutional environments enforce pressures on organisations to validate strategy (Tseng and Chou, 2011). Institutional pressures are thought to force an organisation to conform to guidelines, conventions, expectations and social norms (Dacin, 1997). Conformity to pressures encourages organisations to change structurally and conform to expectations, becoming 'isomorphic' (Slack and Hinings, 1994).

Popularised in modern literature by Meyer and Rowan (1977) they observed that institutional theory enables the explanation of how organisational structures conform to institutionalised myths in order to gain legitimacy. Organisations will align with each other in order to survive the market. DiMaggio and Powell (1983) are credited with addressing this phenomenon through the introduction of isomorphic pressure. To define; isomorphism is the act of companies facing comparable challenges adopting similar strategies to remain legitimate (Dillard et al., 2004). Organisations will become similar by aligning themselves through 'institutional isomorphic change' to gain legitimacy through accepting social norms and rules

[5] Legitimacy is a generalised assumption that corporate actions are desirable, proper, or appropriate. These are considered to be in line with within some socially constructed system of norms, values, beliefs, and definitions (Suchman, 1995)

(DiMaggio and Powell, 1983). These pressures can occur due to internal and external factors such as governments, society, legislation, professional influence and uncertainty (DiMaggio and Powell, 1983). It is thought that institutional theory is effective at highlighting how crucial the institutional environment is in motivating organisations to make changes in the pursuit of social legitimacy (Scott, 2013).

DiMaggio and Powell (1983) established three types of isomorphism which are still considered to be the most accepted forms today, all of which can be seen in the construction industry. These include coercive, normative and mimetic isomorphism. Table 2.4 describes each type of isomorphism and provides examples. The three isomorphic pressures provide conceptions of how behaviour is adopted and how it diffuses based on coercion, mimesis and the transmission of norms (Mizruchi and Fein, 1999). It is thought that isomorphism is more likely to occur during times of uncertainty, which is highly applicable to the current emissions ambiguity in the construction industry (Prue and Devine, 2012). Isomorphic pressure is considered a facilitator of change during periods of uncertainty. Counterintuitively however, during uncertain times, businesses may try and resist change. Isomorphism addresses the notion of organisational homogeneity meaning that in order for businesses to remain the same, some must change (Greenwood and Hinnings, 1996; Prue and Devine, 2012).

The prospect of change in order to remain legitimate is particularly useful in the explanation and understanding of the changes required for introducing sustainable practices into the construction industry. Changes brought about by isomorphism can have a positive impact on organisational change and culture, particularly in the case of construction which is accepted as an institutionalised industry (Prue and Devine, 2012; Kondra and Hurst, 2009, Forster et al., 2015). Additionally isomorphism advocates that in order to be successful, organisations must consider others to align themselves as a critical market player, emphasising a focus on the collective (Aldrich, 2008). Companies do not only compete for customers and economic wealth, but political and social power and legitimacy in order to remain at the top of their industry (DiMaggio and Powell, 1983). Types of isomorphic pressure with construction examples are summarised in Table 2.4.

Table 2.4 Types of isomorphic pressure

Isomorphic pressure	Description	Example in construction	Reference
Coercive	Coercive isomorphism derives from power and influence. In addition to this is can also arise from formal and informal pressures exerted by organisations on other companies upon which they dependent. It also occurs sometimes due to cultural pressures within an industry.	Can be a response to a government mandate. An example of this is the construction industry was seen in the construction skills certification scheme.	(DiMaggio and Powell, 1983) (Prue and Devine, 2012)
Mimetic	Mimetic isomorphism works on the basis of companies imitating each other. This occurs generally during times of uncertainty.	Moehler et al (2008) highlights a specific example of this in construction with the best practice clubs which preceded constructing excellence.	(DeMaggio and Powell, 1983) (Moehler, et al., 2008)
Normative	Normative isomorphism occurs when the informal social rules of an industry have influence over decisions.	It is argued by Moehler et al (2008) that this plays an important role in the UK construction industry with the emergence of the professional system as argued by Winch (2000). The Construction Skills Certification Scheme is also an example of this, it exemplifies how firms adopt new ways of working by aligning with one another in an increasingly networked system.	(Winch, 2000) (Meyer and Rowan, 1977)

2.9.1 Legitimacy in the construction industry

Legitimacy was found to be important in the application of institutional theory; a prospect deemed necessary for remaining competitive (Tseng and Chou, 2011). When the term legitimacy is used in conjunction with isomorphism it is classed as a perception that the actions of an organisation are desirable or part of a socially constructed norm within an industry (Suchman, 1995). There is a generalised perception of what is considered to be legitimate through socially constructed systems (Barreto and Baden-Fuller 2006). Barreto and Baden-Fuller (2006) have argued against the traditional legitimacy influences by advocating a system based on legitimacy groups and providers. They argue that the providers have the ability to assess the conformity of a firm. The providers will then share their inter-organisational knowledge with managers in a two way process (Reger and Huff, 1993), enabling a practice of frequent interaction between groups in order for decisions to be made. Interactive processes will be highly useful for the construction industry where collaboration has been acknowledged as lacking post design phase (Basbagill et al., 2013). The three types

of isomorphism as addressed in DiMaggio and Powell, (1983) will be explored subsequently, beginning with the assessment of coercive isomorphic pressure.

2.9.2 Coercive pressure

Innovation research in the construction industry has highlighted that innovations do not only occur as a result of procedural problems whereby supply chain actors are proactively motivated to make a change. They are also heavily influenced by internal and external institutional pressures (Cao, Li and Wang, 2014; Bossink, 2004; Mitropolos and Tatum, 2000). Studies have indicated that how organisations respond to external pressures is highly dependent on the industry (Bhakoo and Choi, 2013). In the case of construction, the onus is often on the client to provide the driving force for innovation; but they are not always free to innovate due to external or coercive pressures (Ling, 2007; Cao, Li and Wang, 2014).

Coercive pressures are defined as formal and informal pressures inflicted upon businesses, originating from agencies on which the company is dependent (DiMaggio and Powell, 1983; Bhakoo and Choi, 2013). Coercive isomorphism examines compliance to pressure exerted from social, economic, political and legislative requirements (Ashworth et al., 2007; Selznick, 1957). A typical example of coercive pressure in the construction industry was seen in the legislative requirements for health and safety due to previously high levels of industry fatalities (Mendeloff and Staetsky, 2014). Companies were coerced by legislation into changing attitudes, behaviour and procedures to create safer working environments for construction employees (Baxendale and Jones, 2000). It has been noted that coercive pressures are a product of the political rather than the technical approach to organisational influence or legitimate coercion (Ashworth et al., 2007; Scott, 1987).Theoretically these pressures can result in reward for complying with institutional norms (Prue and Devine 2012). Literature on company diversification in order to homogenise and remain legitimate is limited. The only noted work on this concept is Flagstein's (1991) work on diversification in large American companies, which evidence that when one large firm diversifies others do indeed follow according to institutional pressures.

Brotton et al., (2004) furthers this argument by ascertaining that coercive isomorphism is about responding to power, the power of agencies to impose change and new procedures on an industry. A further instance where coercive pressures have been viewed was with the introduction of the Construction Skills Certification Scheme highlighted in Table 2.4. The

legal environment is a driver of behavioural and structural change (Neto et al., 2013). Legal pressures to conform create homogeneity in organisations furthering institutional norms and conformity (DiMaggio and Powell 1983; Neto et al., 2013).The predominant reliance on subcontractors, who account for around 90 percent of all work carried out in construction, means that there is often a reliance on the dominant firm – usually the main contractor (Ayalp and Ocal, 2014; Clough and Sears, 1994; Hinze and Tracey, 1994). There is also a dependence on the client who holds the greatest power in the supply chain (Ryd, 2014).

Reliance on higher forces holds cultural expectations in place creating homogenous industries (DiMaggio and Powell, 1983). Dependent firms often rely on the dominant for survival (Ling et al., 2007). In this case organisations are coerced into adopting innovations in order to participate in the dominant firm's supply chain (Ling et al., 2007). Adopting innovations in line with the dominant company is thought to reflect the commitment to trading relationships, thus companies from the client down will be coerced into adopting new innovative strategies simply to retain business partnerships (Ling et al., 2007).

2.9.3 Normative pressure

Normative and coercive pressures are considered to be similar in nature. Normative pressures differ from coercive as strategies, technologies and products adopted from the impact of normative pressures are voluntary with no guarantee of commitment for business (Lun et al., 2008). Coercive pressures are concerned with the mandatory implementation of innovative strategies whereby firms are almost guaranteed to receive business as a result of the adoption (Lun et al., 2008). In contrast to coercive pressure normative pressures are not driven by legislation and are much less formal, deriving from social pressure, rather than political or legislative forces (Cao, Li and Wang, 2014). The influence of society can be a powerful tool in providing the stimulus for organisations to make behavioural changes, or operational changes in order to conform and remain legitimate among peers (Molleda, 2008).

Being entrenched in professionalised fields cultivates sets of accepted values and beliefs to which companies adjust in order to match specific organisational characteristics (Cao, Li and Wang, 2014). Normative pressures occur as a result of professional standards and social communities within business (Ashworth et al., 2007). These pressures are grounded in convention; they encourage business to seek conformity to appear legitimate within their network (Ashworth et al., 2007). The emphasis is on professional behaviour and the way in

which social norms impact professionalisation from normative drivers (Moehler et al., 2008; Lun et al., 2008). The sense of professionalisation drives social norms which encourage firms to behave in ways which they perceive to be legitimate within their social network (Deephouse, 1996). Interestingly in some cases a coercive pressure can become a normative pressure. An example of this can be seen in the implementation of BIM, backed by government and due to be used on all projects where appropriate by 2016 (HM Government, 2012). The coercive pressure to implement the use of BIM has also morphed into a normative pressure as those in social networks where it is widely used view its implementation. As the application of BIM gathers momentum it ultimately becomes a normative pressure as it develops into a social norm used by key competitors. The pressure to adhere to social norms becomes a powerful component for widespread use as a new development becomes engrained in the industry's psyche. The institutional pressure changes indicate the crossovers which can occur between pressures highlighting their complexity.

In the context of innovative technologies actors within specific fields align to form collective norms and expectations regarding what is considered to be appropriate conduct (Cao, Li and Wang.,2014). Norms are often diffused via collaborative networks in both formal and informal capacities (DiMaggio and Powell, 1983; Teo et al., 2003). The two most important aspects of the task of professionalising an industry are education and collaborative networks, both of which encourage exposure to practices which in turn can become social norms (DiMaggio and Powell, 1983). Clients are considered to be the key actor in building projects. They can be subjected to normative influences via interaction with others who are perhaps forward thinking with the adoption of innovative products and strategies (Cao, Li and Wang, 2014). Exposure to normative influences often leads to greater support for new projects and processes (Cao, Li and Wang, 2014). Normative pressures can also arise from suppliers and customers in the supply chain (Khalifa and Davidson, 2006; Cao, li and Wang, 2014).

Initiators of normative institutional pressures typically set standards for the industry and so therefore other business must follow in order to be selected for contracts (Lun et al., 2008). Additionally, the advancement of normative pressure is thought to be diffused through targeted hiring. An example of which may be found in selecting companies who are already driving sustainability (Zhu and Sarkis, 2007). Norms such as the acceptance of sustainability are thought to be kept in place via education, training and professional bodies (Ashworth et al. 2007). The diffusion of new strategies and innovation, driven through education and training programmes may be particularly problematic in the construction industry. The

fragmentised supply chain structure coupled with the level of subcontracted work could make the diffusion of innovation challenging for industry wide adoption. Fragmentised compartments have encouraged fierce competition for increased profits to the detriment of innovative strategy. Therefore each supply chain compartment remains reticent regarding innovation (Havenvid, 2015). Each project is considered as unique so therefore learnt behaviour from one project may not have far reaching implications for others, particularly in vast subcontracted supply chains (Ayalp and Ocal, 2014; Clough and Sears, 1994; Hinze and Tracey, 1994 Cheng, et al. 2001).

The construction supply chain could aid the explanation of how innovative strategies could be adopted as social norms. Examining the supply chain could increase understanding of supply chain structures and dominant and dependent firms as (Lun et al,. 2008). Firms in construction are highly dependent on each other and their social impact reflects their power sway in the chain. Power is primarily directed from the client at the top, flowing down the chain as companies compete to ensure that the client's contractual requirements are met (Ryd, 2014). All three pressures are thought to play a role in the adoption of strategies by non-dominant firms (Bala and Venkatesh, 2007) i.e. subcontractors. It has been suggested that normative pressures are the most influential pressure in top down supply chain approaches which are customer driven (Son and Benbasat, 2007; Liang et al., 2007). In the adoption of new strategies coercive and normative pressures are thought to be most relevant (Liu et al., 2010).

Normative pressures are crucial in the construction industry as it has become more professionalised with expected norms and standards (Winch , 2000; Lun et al., 2008). As previously alluded to, examples of professionalisation were found with the implementation of the Construction Skills Certification scheme and health and safety measures (Moehler et al., 2008). Organisations are found to align with each other to appear legitimate in complex networked business structures (Meyer and Rowan, 1977; DiMaggio and Powell, 1983). The strong emphasis on tried and tested construction methods highlights the importance of the continuation of social norms in the industry (Blayse and Manley, 2004), suggesting that normative pressures are of key importance in this research. The process by which values become institutionalised may be equally as important.

2.9.4 Mimetic pressure

When businesses view success they often use it as a benchmark to emulate other companies within their social network. The acknowledgement of success reduces perceived risks and increases the uptake of innovative strategies (Zsidisin et al., 2005). One of the most prevalent reasons for imitation in the construction industry is that it is highly competitive. Highly competitive environments do not take on new technology and innovation readily due to associated risks. If one company decides to innovate and is successful others will ultimately follow as viewed success is thought to reduce the perception of risk (Sarrina Li and Lee, 2010). When success is seen it is considered to be the best option to imitate. The two main reasons for imitation are explored in Table 2.5. A study conducted by Massini, Lewin and Greve, (2005) found that out of the three types of isomorphic, mimetic isomorphism was the most widely used method in response to uncertainty in business (Aerts, Cromier and Magnan, 2006; Brouthers, O'Donnell and Hadjimarcou, 2005; Han, 1994; Haveman, 2003; Xia Tan and Tan, 2008) covering a diverse range of industries including health (Starr, 1982) and the civil service (Knoke, 1982).

Table 2.5 Reasons for imitation

	Reason for imitation	Reference
1)	It lowers search costs as organisations are able to duplicate others	(Sarrina Li and Lee, 2010)
2)	Collective knowledge is used to compensate where another organisation may lack	(Brouthers, O'Donnell and Hasjimarcou, 2005)

There are three strategies which are generally followed when imitation occurs. Firstly it may occur based on frequency, i.e. the organisation aligns itself to correspond to other organisations within the same network. The second type of isomorphism is train based isomorphism, occurring when a company imitates firms of the same size. The final type of isomorphism is outcome based imitation, occurring when organisations try to behave the same or mimic the practices of companies who have been successful in the market (Delios, Guar and Makino 2008; Srinivasan, Haunschild and Grewel 2007). Dainty et al. (2007) provide evidence in the construction industry where labour based savings were thought to be the product of mimetic isomorphism. For example when a decision was made to use hydraulic lifts instead of scaffolding, other companies within the industry moved towards this

method. In theory, isomorphism is seen as a crucial mechanism for a firm to be recognised as a legitimate player throughout the industry (Tseng and Chou, 2011).

In industries with high risk or uncertainty, decisions which move towards isomorphism could be accepted with much more confidence than innovative ideas (Deephouse, 1996). The act of imitation itself is considered a legitimate practice (Massini, Lewin and Greve, 2005). The association with uncertainty and risk is avoided in construction by adhering to tried and tested methods to avoid financial failure (Blayse and Manley, 2004). Uncertainty has arguably been underlying the implementation of LCA systems in construction. The vast array of technologies currently available in a saturated market has evinced widespread uncertainty regarding correct product acquisition. The sheer level of technology has made it increasingly difficult for companies to decide upon the use of a particular tool. There also appears to be low demand for products due to the focus on cost, quality and time (Yang and Chen, 2015).

In the absence of legislation for measuring carbon emissions, literature is limited on companies aligning themselves on a particular calculation tool. Current legislation for lowering emissions does not specifically advise on construction although it is thought that the industry will play a critical role in overall carbon emissions reduction (Department for Energy and Climate Change, 2008). Legislative uncertainty and environmental inertia is currently a legitimate action for construction companies. Inactivity regarding the calculation of carbon emissions is considered the norm.

Mimetic institutional pressures encourage companies to align to others, increasing homogeneity, hedging against perceived risks (Zsidisin et al., 2005). It is noted that clients are the main risk bearers in any construction project as they are noted to mimic successful peers to reduce innovation risk and to remain legitimate (Cao, Li and Wang, 2014). Currently it appears to be a legitimate practice to neglect carbon emissions. The addition of environmental practices are seen as a further cost which may increase supply chain risk (Love, et al., 1999; Cheng, et al., 2001; Love, et al., 2004). With the predominant focus on cost, clients actively strive to avoid additional work and costs to keep within budgets.

Organisations mimic each other to provide legitimacy and this is much more likely to happen as a result of ambiguous situations with unclear solutions (Cyert and March, 1963). There are still many gaps in this theory regarding who imitates whom, selective imitation and how good imitations are judged (Barreto and Baden-Fuller., 2006). Some have suggested that

companies use network peers (Haunschild, 1993; Kraatz, 1998; Westphal et al., 1997), others have argued that companies will imitate others of a similar size (Fligstein, 1991; Haveman, 1993; Haunschild and Miner, 1997). Some companies will simply imitate success (Burns and Wholey, 1993; Haunschild and Miner, 1997; Haveman, 1993). There has also been a suggestion that cognitive processes also need to be taken into account (Hambrick and Mason, 1984; Dutton and Jackson, 1987). If environments are complex, decision makers are often left with large volumes of uncertain information on which to base their decisions. In the instance of such complexity, the act of cognitive simplification can aid the decision making process (Huff, 1982; Reger and Huff, 1993; Schwenk, 1984).

As a company grows, greater difficulties are faced with interaction. Individuals become segregated as personal interaction becomes more difficult and this is widely supported in social theory (Simmel, 1902; Durkheim, 1933 and Blau, 1970). The concept of poor interaction is highly reflective of construction supply chain literature which suggests that collaboration in linear supply chain formats creates information dissemination difficulties (Cheng et al., 2001).

2.10 Combining theories: Diffusion and institutional theory

In this research Rogers (1971) diffusion theory will be used in conjunction with DiMaggio and Powell's (1983) institutional theory. Whilst institutional theory can provide explanation of the barriers faced to innovation implementation, diffusion theory can explain how these barriers may be overcome in order to achieve successful diffusion. The research aims to understand how low carbon innovation can be diffused and how it can be viewed as a legitimate practice. Finally it will aim to understand what provides the impetus for companies to take on low carbon innovation in the wake of institutional pressure barriers.

Isomorphic pressures provide explanation for the behaviour of firms who seek to remain competitive. Changes do not occur through conscious efforts to promote change, but they occur naturally due to a chain of events (Prue and Devine, 2012). Pressures which promote conformity occur due to the need for stability and legitimacy within an organisation rather than the aim of creating a competitive advantage (Barreto and Baden-Fuller 2006). Diffusion theory could potentially be very useful for understanding how low carbon innovation can be adopted, whilst institutional theory can be used to understand how an adoption may be

homogenised throughout the industry as a social norm. The use of each theory is summarised in Table 2.6.

Table 2.6 Theory use explanation

Theory	Description	Problem	Reason for use
Diffusion theory	Diffusion theory aids the understanding of the spread of innovation and how it integrates into an industry. It explains the process of the initial innovative concept from its conception through to widespread adoption. (Rogers, 1977; Brown, 1981)	LCA technology is abundant but has not diffused successfully in the industry. Increasing emissions have not improved the use of LCA technology or encouraged the adoption of low carbon decision making processes.	Diffusion theory may help to explain how new emissions strategies and or technologies could be diffused more successfully in the industry, and encourage widespread uptake.
Institutional theory Isomorphic pressure (coercive, mimetic and Normative)	Institutional theory aids the explanation of how companies respond to institutional pressures. The core theme for the application of this is conformity. Companies are subjected to three types of pressure coercive, normative and mimetic in order to seek to remain legitimate their peer group. Pressures are exerted by internal and external agencies (coercive), social expectations (normative) and uncertainty (Mimetic) (Prue and Devine, 2012; Cyert and March, 1963; Bhakoo and Choi, 2013)	LCA is not seen as an important aspect of construction legitimacy.	In the absence of legislative requirements for low carbon decision making strategies movement towards sustainable buildings remains slow. Low demand and expected norms to remain inert to environmental action have encouraged environmental inertia. Isomorphic pressures can help to explain the impact that institutional pressures have on aiding or inhibiting the uptake of LCA.

The reason behind the combination of these two theories is that many scholars have found that the use of institutional theory and isomorphic pressure can be effective at explaining homogeneity throughout an industry. The construction industry is generally homogenous in nature, following accepted paths which are fixed through institutional pressures. It does not however explain how those who wish to use innovative methods break away from norms, overcoming institutional barriers to implement new processes. The use of diffusion theory can aid the explanation of lead innovators, explaining how and why those who diverge from the set path can create legitimacy through long term success, overcoming sustainability

barriers (Rogers, 1971). In essence by using these two theories an understanding of how a new process could be integrated into an industry and how it could ultimately become common practice as part of the institutionalised norm can be understood.

2.11 Development of research questions

After assessment of the literature the clear gaps in the calculation of carbon emissions appear to be in the behavioural elements of carbon calculation, namely collaboration, supply chain integration and the decision making process. Currently the focus for the calculation of CO_2 emissions has been scientific and firm focussed in nature. Research has shown that this is problematic for total emissions calculation as supply chain inputs are disregarded, or the information is unobtainable. In addition the supply chain is linear in structure which makes communication between key supply chain actors difficult. Although the scientific technology is valued, the importance of collaboration and communication from the conception of the project has been overlooked. In order to explain the phenomena of rising CO_2 and the potential solutions to this problem in the construction industry both Rogers (1971) diffusion theory and DiMaggio and Powell's (1983) institutional theory will be used as a theoretical framework aiding the understanding of what is happening. The following research questions have been formed from this review (see Table 2.7.)

Table 2.7 Development of research questions

Research Question	Literature gap
RQ1) How can low carbon decision making strategies diffuse throughout the construction industry?	There are vast amounts of LCA technology available in the construction industry however CO_2 emissions are continuing to rise. Low carbon calculation or low carbon decision making strategies, scientific or social have not diffused successfully. It is currently unknown why this is happening, and how it be improved. RQ1will aim to understand the reasons behind why the diffusion of such products has been unsuccessful and how low carbon decision making strategies can be successfully diffused throughout the construction industry.
RQ2) How can low carbon decision making strategies improve a firm's legitimacy in the construction industry?	Firms in all industries seek legitimacy in order to be considered as a valid player in their field. This is often achieved through legislation, mimesis or the transition of norms through the supply chain. Although the industry is aware of low carbon technologies, they are not currently accepted as being a cornerstone of a construction company's legitimacy. This question aims to address how low carbon decision making strategies, encompassing both technology and working practices can be made into an essential part of construction company legitimacy in the future.
RQ3) What provides the impetus for companies to take on low carbon decision making innovations?	The literature has addressed that in order to take on sustainability strategies there will almost always be an element of innovation and risk. LCA technologies and low carbon strategies are often innovative in nature primarily because in LCA in construction is still considered to be it is in its infancy. With innovation comes risk, something which is avoided in the construction industry. A particular literature gap that has been found is

	centred around understanding what makes people take on new innovations in construction or what provides the impetus. Diffusion theory will aid the understanding of this. It is hoped that by addressing innovation stimuli, the formula for how innovative lower carbon emissions strategies within the construction industry can be adopted. in the industry can be adopted.

2.12 Chapter summary

Chapter 2.0 was designed to explore the literature behind lifecycle analysis in the construction industry. The purpose was not simply to explore the scientific grounding of CO_2 calculation methodologies and technologies. It also aimed to address the underlying structural issues and social behaviours which may have an effect on the development and implementation of low carbon decision making processes. The chapter has assessed the literature in the following areas:

- The construction supply chain
- LCA calculation methodologies and technologies
- Sustainable construction barriers and enablers from technological, structural and behavioural standpoints.
- Holistic approaches to LCA

These areas have been evaluated to understand whether the core issues which underpin the lack of low carbon decision making strategy in the construction industry are technological or behavioural. By addressing both concepts research questions were formulated from the gaps found in the literature. These research gaps were consistent with structural and behavioural factors as being the most problematic issue when formulating low carbon decision making strategies in the construction industry. The research questions were constructed and framed with the appropriate theoretical lenses, aiding the research design. Both diffusion theory and institutional theory were chosen due to their focus on innovation, legitimacy and behavioural concepts. In order for any technology to be successful, it must be diffused positively and it must reach a point whereby a company not adhering to a new concept is considered as an illegitimate player in the field; assisting the explanation of how low carbon decision making strategies in the construction industry can be more easily integrated and become the norm.

Chapter 3.0 – Methodology

3.1 Chapter overview

The methodology chapter of this research is concerned with the methods undertaken to collect research data for analysis. It assesses the philosophical assumptions which provide the foundation for the chosen methods. These methods are used to aid the realisation of the research objectives. The research was preceded using an interpretivist approach; therefore the methodology focuses on this epistemological viewpoint and corresponding ontological position. Alternative methodological positions were also discussed and contrasted in support of the research design. The review of the literature in the area of construction CO_2 life cycle analysis (LCA) highlighted that the most prominent gap in the current research is centred on the human behavioural elements of LCA. Vast amounts of LCA technology with the ability to calculate emissions and inform low carbon decision making has not been successful in enabling the industry to lower emissions. The claim is justified by the fact that CO_2 outputs continue to increase in the construction industry (Green Construction Board, 2012; Strategic Forum for Construction, 2010).

Acknowledgment of a saturation of technology based studies has provided the foundation for the research. It has informed a movement away from technology based emissions studies, towards the social dimension of emissions calculation using supply chains and management theories; bypassing technological and statistical emissions research for behavioural centred study. The methods discussed in this chapter focus on a qualitative methodology. The quantitative paradigm will also be discussed in the justification of the qualitative research design and the way in which it will inform the outcomes of the research questions. Finally this chapter will outline how the research was developed using the key literature themes, the use of focus groups, interviews, ethical procedures and sampling methods.

3.2 The research questions

The literature review findings were instrumental in the development of the research questions. The questions were formulated in line with research gaps found in the human behavioural aspects of low carbon decision making. More specifically the gaps in the literature were centred on business legitimacy perceptions regarding the use of LCA and recognising the institutional pressures which inhibit or aid the development of sustainable

buildings. In addition there was also a need to understand what drives companies to move beyond social norms and implement innovation. The following three questions acted as drivers in the development of the research, informing in part, methodology and analysis.

RQ1. *How can low carbon decision making strategies diffuse throughout the construction supply chain?*
RQ2. *How can low carbon decision making strategies improve a firm's legitimacy in the construction industry?*

RQ3. *What provides the impetus for construction companies to take on low carbon decision making innovations?*

3.3 Research paradigms

One of the most important issues to assess when producing a research design is the paradigm in which the research fits. Kuhn (1962) is credited with the modern definition of a paradigm as being

> *'A universally recognised scientific achievement that, for a time, provides model problems and solutions for a community of practitioners'* (Kuhn, 1962: 10).

A further explanation of a paradigm has been provided by Guba and Lincoln (1994). In this study, a paradigm represented a particular view of the world based on the beliefs of the individual. The researcher's view of the world informs the choice of research paradigm (Bayley, 2013). These views theoretically inform the methods used to collect data. So important is the concept of methodological viewpoints and paradigms, that the questions concerning the methods used in collecting data are considered secondary to the researcher's paradigmatic preference. The paradigm in which the researcher sits reflects his or her underlying assumptions and shared values about the world. It is the researcher's understanding of the world which will drive the development of the investigation (Kuhn, 1962; Bayley, 2013). The paradigmatic predispositions of the scholar will always be used to inform the data collection method. From this, the researcher will construct the research methods via the ontological and epistemological positions that he or she adopts (Guba and Lincoln, 1994). The core ontological and epistemological drivers of social research will be discussed in the subsequent section.

3.4 Epistemology and ontology

Ontology and epistemology are described as the foundation of all social science research as they generate the research process (Bayley, 2013). Ontology is defined as the nature of reality (Hudson and Ozanne, 1988), whereas epistemology is defined as the relationship between the researcher and reality (Carson et al., 2001). There are considered to be two forms of opposing ontological views which can be traced back to 515BC. These are referred to as the ontology of '*being*' and the ontology of '*becoming'*. These two forms of ontology are explored in Table 3.1.

Table 3.1 The ontology of *being* and the ontology of *becoming*

Ontology	Explanation	Philosopher	Reference
Ontology of *being*	Lack of form in reality and persistent chaos. Reality constantly changes.	Heraclitus c. 535–c. 475BC	(Gray, 2009)
Ontology of *becoming*	Reality is clearly formed. It has identifiable properties and reality is permanent and unchanging.	Parmenides c. 515–c. 445BC	(Gray, 2009)

The ontological beliefs of the researcher are central in the research development. The two forms of ontological perspectives provide the sense of dichotomy between the two paradigms of qualitative and quantitative research. It is acknowledged that the ontology of *becoming* is the predominantly accepted ontological viewpoint (Grey, 2009) supported by Popper's 1959 falsification of theory model (Popper, 1959). The concept advises that reality is clearly formed and scientific formulae are utilised to understand one single and stable reality. Reality can be proved or disproved through the testing of hypotheses.

The ontology of *being* differs from this viewpoint as it advocates chaos and unformed structures of reality (Grey, 2009). Reality is constantly changing as human feelings and emotions undergo modification dependent on external inputs. Therefore reality is what is real to the individual, not a general and uniform reality for society. It is argued that reality is mutually constructed between people through interaction and does not exist externally (Grey, 2009). The absence of external reality as a viewpoint is generally expressed through the use of qualitative methods. It has been argued however, that epistemological positions which are traditionally associated with the quantitative paradigm should not be disregarded. Theoretically both paradigms address the theory of fact, attempt to understand human life and

evaluate the research process (Reichardt and Rallis, 1994; Sale et al., 2011 and Casebeer and Verhoef, 1997).

Objectivist epistemology advocates the position of the ontology of *becoming* i.e. objective reality (Gray, 2009) but does not reject subjectivity. There is a belief that objective reality is there to be found, it is not created but it can be discovered by studying human thought processes which are subjective (Bunge, 1993). The essence of this concept grounds itself in the notion that subjectivity should not always be rejected, providing the subjective views are assessed objectively (Bunge, 1993). The converging of these ontological and epistemological perspectives is perhaps more suited to mixed methods research. Most researchers however, will naturally fall into one paradigmatic and ontological division; it is this perspective which will inform the ontological standpoint of the researcher. There are considered to be three epistemological perceptions these include objectivism, subjectivism and constructivism. These three concepts are explored in Table 3.2.

Table 3.2 The three primary epistemological positions

Epistemological position	Description	Reference
Objectivism (positivist theory)	Objectivists believe that reality exists apart from any consciousness. Understanding and social values are objectified in study participants. It is thought that appropriate methods can discover the objective truth about phenomena.	(Gray, 2009) (Busher and James, 2012) (Crotty, 1998)
Subjectivism	Subjectivists advocate that there is an existence of an external reality but the nature of reality is discovered through individual consciousness. Therefore, meaning does not emerge from interaction but it is imposed on the object by the subject.	(Gray, 2009) (Busher and James, 2012) (Crotty, 1998)
Constructivism (interpretivism)	Constructivists believe that meaning ultimately emerges through engagement with world realities, and so therefore reality is constructed not discovered.	(Gray, 2009) (Busher and James, 2012) (Crotty, 1998)

These positions exist on a scale with objectivism being most associated with the quantitative paradigm, positivism and the belief that reality is constant and can only be discovered objectively (Gray, 2009; Busher and James, 2012; Crotty, 1998). At the opposite end of the spectrum lies constructivism, most highly associated with the qualitative paradigm, interpretivism and phenomenological study (Gray, 2009; Busher and James, 2012; Crotty, 1998). The core values of constructivism highlight that reality emerges through engagement

and so therefore is socially constructed. Theoretically, many world views can exist simultaneously and there is no single reality (Grey, 2009; Crotty, 1998).

Once the ontological and epistemological position of the researcher has been outlined, the research design can begin. The methodological viewpoints are pivotal in the development of the data collection method. Table 3.3 highlights how this selection may take place by assessing ontological, epistemological, and theoretical perspectives of research methodology. It indicates how epistemological, ontological and theoretical factors influence the research methods. Heavily quantitative studies sway towards the theoretical approach of positivism which is underpinned by the objectivist epistemology (Guba and Lincoln, 1994). Conversely, the qualitative researcher favours the phenomenological approach to research which is underpinned by constructionist epistemological perspectives (Guba and Lincoln, 1994).

Table 3.3 Ontological and epistemological theories and methodologies

Quantitative → **Qualitative**

Item	Positivism	Post Positivism	Critical theory	Constructivism
Ontology	Only one real reality and one truth. Apprehensible.	Notion of critical realism. Imperfect but real reality. Probably apprehensible.	Concept of a virtual reality which is shaped by social values which have been developed over a period of time.	Relativism – constructed realities
Epistemology	Objectivist. Avocation of fact based research.	Objectivist, findings are probably true.	Subjective	Subjective – created findings.
Methodology	Testing of a hypothesis using primarily quantitative methods	Modified experimental. Falsification of hypotheses – can also include mixed methods	Dialogue	Dialogue, hermeneutical

(Source: Guba and Lincoln, 1994)

3.5 Positivism

Perhaps the most recognised objectivist position is positivism; this standpoint advocates that there is one single reality to any question and this is regardless of the interviewers' belief (Carson et al., 1988). The positivist researcher will use controlled methods which are usually structured in nature (Gray, 2009). As a positivist researcher, research topics will be identified, questions constructed, hypotheses generated and appropriate methods for the research will be

established (Bryman and Bell, 2007). The researcher will remain as a separate entity and distance will always be maintained between the researcher and the participant as the findings should theoretically remain unaffected by the researcher (Remenyi et al., 1998). One of the most important aspects of this paradigm is that the researcher remains completely emotionally neutral. Emotional neutrality occurs so that the participant is not influenced. Positivists seek objectivity to establish facts only and employ a clinical approach to research. Statistical methods are often used to seek generalisations in results (Hudson and Ozanne, 1988).

The quantitative paradigm is based on positivism (Bryman and Bell, 2007). Positivism advocates that the key purpose of research is to generate hypotheses which can be 'scientifically' tested (Bryman and Bell, 2007). It promotes the scientific process of gathering facts in an objective way. It is thought that through the use of correct methodological approaches reality can be understood. The ontological perspective of the positivist researcher is that reality is objective and that there can only be one truth (Sale et al., 2002). The 'real' truth must be discovered and understood through the use of scientific, objective and testable means (Sale et al., 2002). A criticism of the quantitative paradigm is that it conveys simplicity in truth and this is fundamentally expressed through generalisations without contextual meaning (Guba and Lincoln, 1994). In addition to this, when researching human behavioural impacts it is extremely difficult not to influence outcomes (Clissett, 2008). The researcher will indirectly form a relationship with the participant either in person or through the wording found in the line of questioning or survey (Guba and Lincoln, 1994). Regardless of the problems experienced with such research methods, quantitative research has developed the scientific validity of social studies as numerical evidence is used to support findings (Ghoshal, 2005).

3.6 Interpretivism and phenomenological studies

The concept of interpretivism is considered to be the opposing view to positivism (Guba and Lincoln, 1994). It encapsulates subjectivity, contextual analysis and movement away from the endeavour to understand phenomena from a statistical viewpoint. It aims not simply to acknowledge what is happening but explains why through meaning (Merriam, 2002). The fundamental origin of the qualitative paradigm is formed around the epistemological concept of interpretivism (Altheide and Johnson, 1994; Guba and Lincoln, 1994). Interpretivists advocate the notion that there are multiple realities and multiple truths associated with any

research subject; these are the product of the researcher's own interpretation or construction of reality (Sale et al., 2011). The primary focus of this paradigm is that reality is socially constructed and so therefore constantly changing (Berger and Luckman, 1991).

> *'The sociology of knowledge is concerned with the analysis of the social construction of reality'* (Berger and Luckman, 1991:15).

The very nature of interpretivist research means that it is often difficult to interpret multiple meanings from multiple realities (Lincoln and Guba, 1985). The generation of knowledge from this epistemological position is perceived as being socially constructed (Carson et al., 2001); in part due to the interactive methods used in qualitative research. The researcher develops a rapport or relationship with the participant from which mutually created findings arise (Berger and Luckman, 1991). The use of qualitative methods has enabled the movement away from the falsification of theory concept established by Popper (1959), a concept still used to drive quantitative research today. Qualitative research aims to challenge the boundaries of statistical and scientific approaches to prove or disprove hypotheses; it moves towards providing meaning to research findings through interpretation and understanding the participant's world (Kvale, 2007). It does not simply provide factual information which can be proved or disproved through the quantification of generalised themes (Kvale, 2007). Qualitative research enables the exploration of complex human interaction and behaviour which has a direct impact the subject. The core philosophy of this methodological perspective is that meaning and behaviour cannot be generated by an external reality, but are created through the experience of the participant and researcher (Cohen and Manion, 1994).

3.6.1 Phenomenological study

Phenomenological studies along with interpretivism advocate that reality is socially constructed. Reality is created and given meaning by people through human experience and behaviour (Easterby-Smith et al., 2000). Phenomenology suggests that we cannot fully separate ourselves from our own view of reality, therefore it enables us to question whether reality is what is real for us, rather than what is real for society as a whole.

The central tenet of this research is that human behavioural patterns are the key to understanding the environmental impact of construction CO_2 emissions. Thus qualitative enquiry has been selected as the most appropriate data collection method to facilitate this

study. As emissions continue to rise despite technological advancement, the aim of this research was to proceed from a phenomenological and interpretive standpoint, augmenting the traditional scientific focus of CO_2 calculation methodologies in the construction industry. An interpretive and qualitative perspective enables the researcher to understand the perceived realities of the problem and give it meaning, rather than providing continued quantitative assessment through technological foci on current LCA methods. From a phenomenologist's viewpoint the contextual understanding of why emissions are rising and how they can be reduced is key to understanding the problem through social interaction and interpretation, not clinical observation (Neuman, 2000). Therefore the purpose of this research was to interpret behavioural impacts on emissions measurement in order to develop future emissions practices, not simply to observe and comment on behavioural patterns (Goulding, 1999).

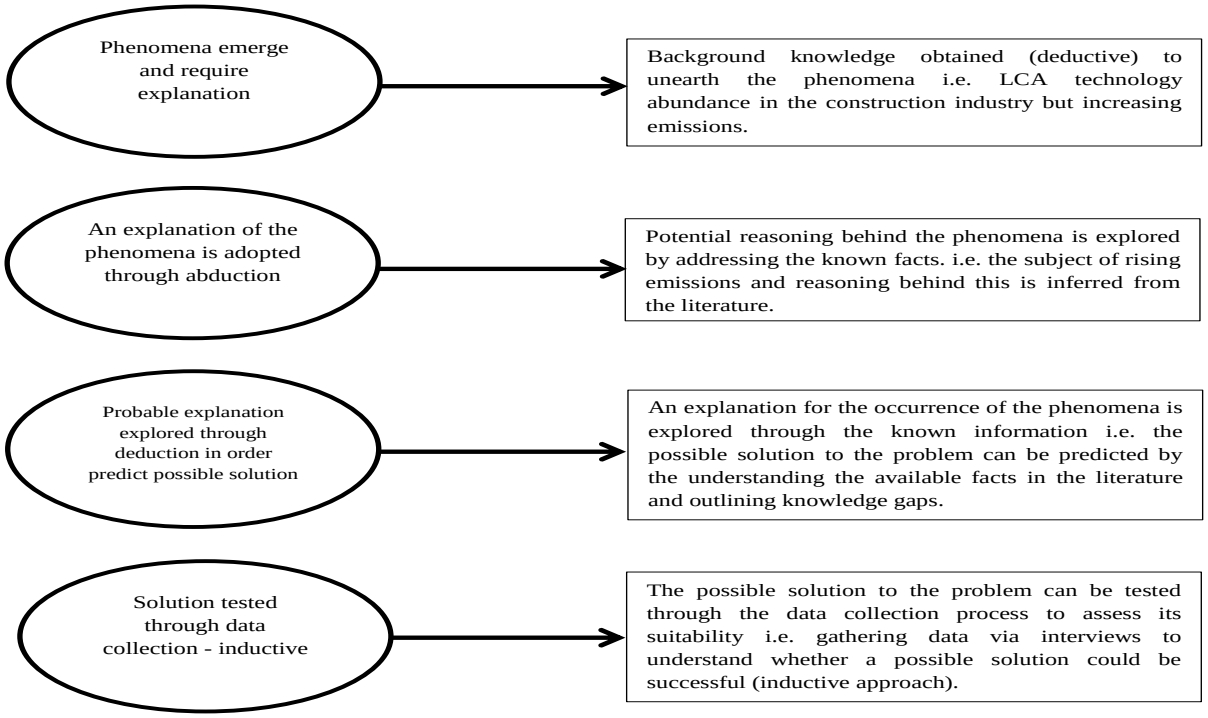
Although interpretivist researchers are instinctively drawn to inductive research, in reality inductive, deductive and abductive methods are used in the research process. Abduction, deduction and induction were a derivative of Aristotle's work. Its reintroduction and into the present was led by the philosopher Charles Sanders Peirce (Mirza et al., 2014; Eriksson & Lindstrom 1997; Peirce, 1932). Trochim (2006) provides an overview of the deductive and inductive approaches to research arguing that ultimately it can be guileless to view the two as dichotomies (Trochim, 2006). The two approaches differ in the sense that inductive reasoning takes the form of a 'bottom-up' approach. Using this method, observation is followed by the recognition of patterns forming tentative theory and ultimately the generation of an overarching theory (see Figure 3.1.) Deductive reasoning is often classified as a 'top-down' approach (see Figure 3.2.) In this method tentative theory is established at the commencement of the study through significant background knowledge, this in turn forms a tentative premise of potential outcomes. The next stage of observation and analysis will lead to either the confirmation or disconfirmation of theory (Trochim, 2006).

The abductive reasoning approach is seen as a way to introduce theories to explain facts (Dong, 2015). It is considered to be the only logical way to introduce new ideas (Peirce, 1932), bringing together complex and contradictory information to generate insight and create new solutions to problems (Kolko, 2010). Abductive approaches to research are a form of inference in which patterns of phenomena are recognised by incorporating and rationalising ideas in order to develop knowledge (Mirza et al., 2014; Raholm, 2010). Abductive reasoning guides the generation of research concepts which are ultimately

extracted logically through both deductive and inductive reasoning. It enables the conception of ideas from vague concepts whilst deductive and inductive reasoning enable the processing of those ideas (Raholm, 2010; Eriksson and Lindstrom, 1997). It was developed as it was thought that the idea of generating a hypothesis for research was merely a guess and the generation of new ideas are not discovered logically (Mirza et al., 2014). The purpose of using an abductive approach was to uncover logic through which new ideas can be discovered (Fann, 1970). New ideas are invented to describe patterns of phenomena (Peirce 1903). However Pierce also recognises the importance of further explication through deductive reasoning via the acquisition of background data and the support of that via empirically driven inductive reasoning (Mirza et al., 2014). The process of using abductive reasoning is explained in figure 3.1, highlighting the crossover between research methods.

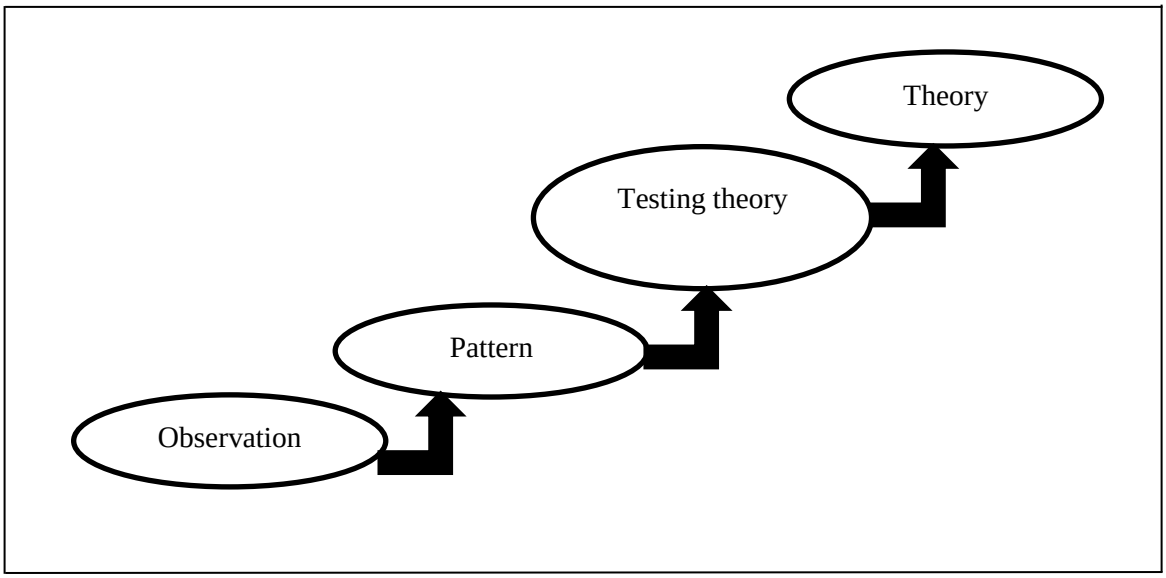
The research carried out in this thesis has taken on aspects of all three types of reasoning however it leans more towards an abductive approach with deductive and inductive elements. Theories were selected at the early stage of the research in order to offer an explanation of the phenomena through a theoretical lens, providing an informed logical explanation and solution to the potential problems with the development of LCA in construction. The research commenced with significant background research into the literature to acquire knowledge on the subject which is reminiscent of the deductive approach. The acquisition of knowledge enabled the establishment of a series of phenomena which directly impact on the subject i.e. background knowledge obtained from the literature review enabled the establishment of the problem and a pre-empted explanation and understanding of the problem trough abductive means. A probable solution to the problem was then outlined and tested using qualitative data collection methods, most commonly associated with the inductive approach. The interpretive and abductive approach to the research enabled the exploration of the subject whilst simultaneously providing flexibility to alter theories and outcomes in line with the evidence.

Figure 3.1 The abductive reasoning approach



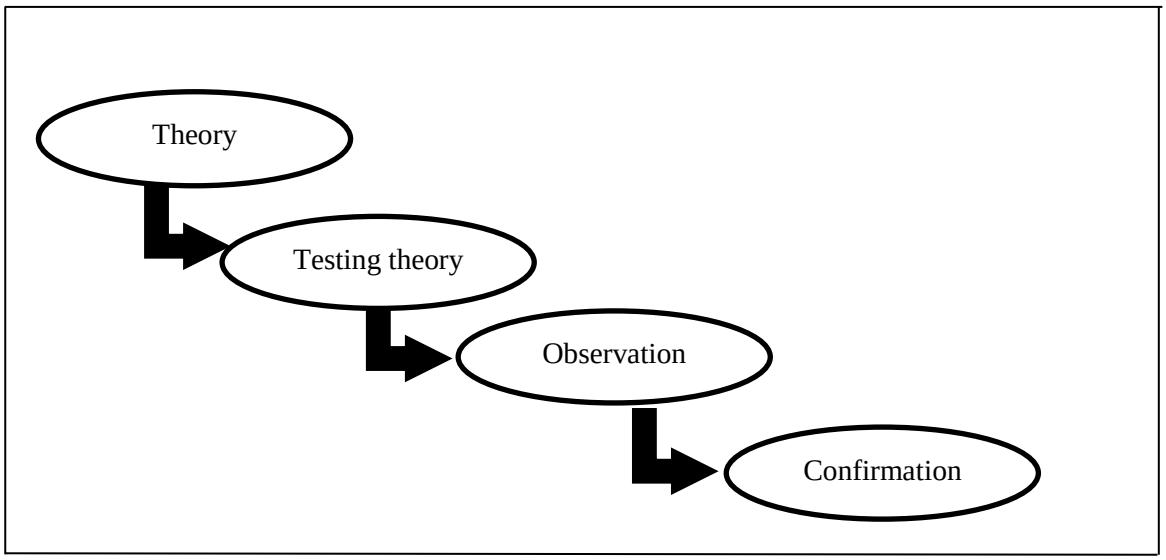
(Haig, 1999; Lawson and Daniel, 2011; Raholm, 2010; Mirza et al., 2014)

Figure 3.2 Inductive reasoning approach



(Trochim, 2006)

Figure 3.3 Deductive reasoning approach



(Trochim, 2006)

3.6.2 Qualitative and quantitative methods

Once the key methodological viewpoints of this research were considered the methods of data collection were then formulated. The phenomenological and interpretivist approach of this research supports the use of qualitative methods as the most appropriate choice for data collection. Qualitative methods were addressed and focussed upon in this chapter however quantitative methods were also discussed as justification for the use of qualitative research. Research paradigms generally fall within two categories of research method, qualitative and quantitative. Qualitative research differs from quantitative in that it does not isolate the analysis of the results from the researcher's experience (Mills, 1959). Qualitative data provides rich data sets, enabling the researcher to gain understanding through a natural communicative process (Mack et al., 2005). The experience of the participant is exuded on the researcher enabling an opportunity for the researcher to experience the subject as personally as possible (Miles and Huberman, 1994). Qualitative methods are also used in situations where the problem is complex as it enables the exploration of a wide subject area (Guercini, 2014). Qualitative methods were considered the most appropriate for this research as there was a need to move away from the heavily statistical quantitative approaches to emissions analysis. By using a qualitative approach a clear methodological gap in the knowledge was filled. Additionally, a qualitative method enabled a movement away from simply highlighting what was happening in the industry surrounding emissions analysis

towards explaining why through the acquisition of rich data sets gathered from a communicative data collection process. An explanation of the way human behaviour impacts emissions analysis in the construction industry was an integral part of the research.

3.6.2.1 Problems faced in qualitative research

Although qualitative study is said to provide richer data outputs it has come under scrutiny. Methods of qualitative data collection have been considered too subjective and interpretive (Silverman, 2000). The interpretive nature of this research has led to debate surrounding how valuable qualitative data collection is, particularly from an ethnographical view point (Nastasi and Schensul, 2005). The key challenges faced by using his method include bias, reliability and ethical doubts (Chenail, 2011; Morgan and Smircich, 1980; Houghton et al., 2010). These key issues are discussed in the next sections with acknowledgement of how these concerns were overcome in this research.

3.6.2.2 Bias

Bias is a consideration of all research types and has been a consistent challenge in social research (Chenail, 2011). It is a particular concern in qualitative studies primarily due to the researcher/participant relationship and the subjective nature of analysis (Casey, 2004, Kapoulas, 2003). When the relationship between the researcher and the participant develops, it becomes increasingly difficult to separate personal thoughts and beliefs that may have an impact on the research (Bogdan and Biklan, 1982). As the epistemological assumptions advocate the notion of mutually created findings, the involvement of the researcher can in essence develop the outcome through personal inputs (Berger and Luckman, 1991). The two main types of bias associated with qualitative research are sample bias and instrument bias (Machens et al, 2008). Both of which are examined in Table 3.4.

Table 3.4 Qualitative study bias

Bias type	Description	Reference
Instrument bias	Instrument bias is focussed on the researcher's ability, as he or she is the research instrument. All information gathered during the data collection process is analysed by the researcher who will have their own views on the data. They will also have formed relationships with the participants, often due to the interactive and personalised nature of qualitative research.	(Denzin and Lincoln, 2000) (Marshall and Rossman, 1995) (Patton, 1990) (Rajendren, 2001)

Bias type	Description	Reference
Sample bias	Sample bias is challenging for qualitative research, sample sizes are often small but must achieve the data aims. The samples are often chosen for convenience and are much smaller than those found in quantitative research.	(Machens et al, 2008) (Mutchnick and Berg, 1996) (Berg, 1998)

3.6.2.3 How bias has been overcome in this research

As this research uses qualitative methods the issue of bias within the sample was taken into consideration. As the researcher is solely responsible for selecting potential participants, care was taken to ensure that all participants in the research met the appropriate criteria for inclusion in the study; this was essential as an ill-advised sample can limit the overall effectiveness of the research (Collier and Mohoney, 1996). Bias was avoided as much as possible through careful participant selection. Study subjects were chosen based on their knowledge of the subject area in order to avoid convenience bias as much as possible. The sample size was dependent on data saturation but theoretical sample sizes were also taken into account (Glaser and Strauss, 2009). The literature suggested that twenty interviews were considered to be within the range of acceptability (Creswell, 2000). Other studies suggested a range of six to ten interviews for phenomenological studies (Denzin and Lincoln, 2011; Kuzel, 1999; Morse, 2000). Care was also taken not to display personal viewpoints regarding the questions as much as possible to aid the reduction of instrument bias.

3.6.2.4 Reliability and validity of qualitative research

The interpretive nature of qualitative research has led scholars to question its reliability (Clissett, 2008) as the discursive method allows meaning to be given to the findings which are inherently subjective. Meaning can also be provided through many different perspectives and so therefore reliability of evidence can be difficult to prove (Morgan and Smircich, 1980). Difficulty with proof is often acknowledged through the lack of statistical outputs which can generalise results; in addition to this the difficulty with replicating the results has also been deemed a problem (Kapoula, 2012).

In qualitative research, the context of the data and the meaning is key as results are not fully replicable, inhibiting the theory of reliability being proven through repeatability of the research promoted in quantitative study (Chia and Holt, 2008; Devinney and Siegal, 2012). The inability to fully replicate results has been acknowledged as one the most problematic issues for qualitative reliability (Kapoula, 2012). The replication argument, however, has

been disregarded by qualitative scholars who have argued that using quantitative replication as a criticism is simply too simplistic and vague for understanding qualitative research (De Ruyter and Scholl, 1998).

The number of methods that the researcher uses to access data is considered to increase reliability as higher volumes of evidence are accessible (De Ruyter and Scholl, 1998). Evidence can then be analysed, cross referenced and statements can be supported directly by the data collected. Many arguments have been put forward regarding reliability in qualitative research. Some have argued that reliability must be redefined free from scientific context (Strauss and Corbin, 1990). Others have argued that for qualitative research, reliability is not a concern as human emotions are not constant; they are changeable but are correct at the time of contact (Stenbacka, 2001). On this issue Lincoln and Guba (1985) are heavily cited arguing that it is validity of qualitative research that is essential, not reliability.

There is a clear lack of consensus in literature covering validity of qualitative study. Whilst some such as Clissett (2008) argue that the sample size is imperative, others suggest validity lies in the way in which the results are processed i.e. the rigour, quality and trustworthiness with which the results are analysed (Lincoln & Guba, 1985; Mishler, 2000; Stenbacka, 2001). The primary issue is that the data instrument is the researcher, not an objective tool. The outcome of the research is a result of the researcher being entrenched in the data collection process. The researcher playing the role of the research instrument will interpret and reflect upon the results and will be responsible for their credibility (Clissett, 2008; Patton, 2001; Goladshini, 2003). If the researcher defines each task and clearly illustrates the ontological and epistemological perspective, actions can be deemed as defensible; therefore the research can be accepted with confidence (Mishler, 2000). Reliability and validity will always challenge qualitative researchers due to the subjective nature of the process. In this research it has been extremely important to consider the challenges in the reliability of qualitative data. Details of the research perspective at each stage of data collection have been explained throughout the study which was vital for increasing reliability and validity of the research.

3.6.2.5 Ethical considerations

A further consideration which is important in human based research is the issue of ethics. The interpretive and communicative nature of qualitative research creates unpredictability, which to some extent can be out of the researcher's control (Houghton et al., 2010). One of the most

useful aspects of qualitative research is the large amount of information which the researcher will gather from the participant, most of which is personal (Patton, 1990; Rajendren, 2001). In order for this to comply with institutional regulations it is essential to gain consent from all those who take part. The risk/benefit of the research must also be explained and information must remain confidential at all times (Houghton et al., 2010). Table 3.4 explains these considerations in relation to the research. Ethical considerations for both phases of the research are addressed fully in section 3.9.2 and 3.11.2.

Table 3.5 Ethical considerations

Ethical consideration	Description	References	Application to research
Informed consent	Can be difficult to obtain as due to the deductive approach of qualitative study it can often be a complex procedure to know what consent is being obtained for	McDonnell et al., 2000; Holloway and Wheeler, 2002)	A circumstance was found in this research. The research initiated data collection with a focus group which was changed to 1-1 interviews. All participants were asked to fill in a consent form prior to any data collection taking place.
Researcher/participant relationship	Researchers and participants build up a rapport and so therefore the relationship can become personal and exploitative in nature. Boundaries can become blurred and may have indirect harm which was not initially perceived	Houghton et al., 2008; Casey, 2004, Kapoulas, 2003)	Only two participants in this research were previously known to the researcher and each interview was limited to an hour so that the participant/researcher relationship remained professional.
Risk and benefit	The potential risk factor for a participant must always be assessed i.e. divulging sensitive company information may lead to job loss	(Cutcliffe and Ramcharan, 2002)	The participant was assured that at no time will their identity be revealed and questions asked were generalised and not company specific. It was agreed that the potential benefits to the researcher in this case outweighed the risks.
Confidentiality	Confidentiality can be extremely difficult to maintain in qualitative research, due to the descriptive nature of the findings	(Houghton et al., 2008)	A number of measures were put in place so that participants would remain anonymous at all times. Names were removed from all transcriptions, recordings were securely stored and all participants were referred to as a letter i.e. 'Participant A'. In addition to this no company names were revealed.

3.7 Research method and design

The review of the literature highlighted that regardless of the vast array of emission calculation software, CO_2 is continuing to increase in the construction industry (Strategic Forum for Construction, 2010). The focus on statistical and scientific methods in carbon calculation and low carbon decision making has enabled a research gap to emerge. The focus on mathematical and technological solutions to the emissions problem has focused academic attention away from the deep rooted behavioural causes and solutions to CO_2 emissions. A lack of research in this area has provided the impetus for this study to take on a human centred approach for addressing the carbon emissions problem. It is not the purpose of this research to assess how low carbon decision making can be eased statistically, but rather it aims to understand the institutionalised behavioural problems encountered in the implementation of LCA. It aims to gain a more informed understanding of why emissions are continuing to rise despite technological improvement, offering a human centred solution to the problem.

3.7.1 Sampling procedures

In any study the most useful data collection process would theoretically enable the researcher to investigate the entire population of an industry (Acharya, 2013). However due to the vast numbers of interviews, surveys and data collection processes this would take; it is simply not an option. Therefore a sample of that population must be selected.
A sample is a

> *'Segment of a population that is selected for investigation'* (Bryman and Bell, 2007: 176).

The sample is important in social research as the outcomes of the study are dependent on information the participants provide; its design in qualitative research is one of the most challenging aspects of the research strategy (Bryman and Bell, 2007). The participants chosen must provide validity and in addition to this must be adequate enough to achieve the research aims (Uprichard, 2013). There are two types of sampling procedures which can be used in social science research; probability sampling and non-probability sampling. Articles which are specifically centred on sampling strategies are generally considered to be narrow and specific to a particular subject which makes following effective sampling theory difficult in

original research (Karney et al, 1995; Mahaffey and Granelo, 2007; Onwuegbuzie and leech, 2007).

In this research non-probability sampling was considered to be the most appropriate method as participants were chosen based on their supply chain position. Particular groups were targeted as their knowledge was required in order to provide an overall picture of the supply chain i.e. architects and sub-contractors. In addition to this, further contacts were made via participants. Probability sampling was not considered as the most appropriate sampling method for this research as this method is considered as a sampling approach to test hypotheses through generalisation (Acharya, 2013). Using an interpretivist approach the aim of the research was not to generalise but to explain how and why a phenomena may be occurring (Marshall, 1996). Therefore non-probability sampling was considered as the most successful method for the progression of this research. Table 3.6 shows the four main types of non-probability sampling.

Table 3.6 Non probability sampling overview

Non-probability sample type	Description	Strengths	Weaknesses	Reference
Convenience sampling	A convenience sample is a sample which is simply available to the researcher.	Participants are easy to find. Generally high response rates Useful for pilot studies. Low cost	Not possible to generalise findings. Lacks credibility	(Bryman and bell, 2007) (Marshall, 1996) (Acharya et al., 2013)
Judgement/ purposive sampling	The most common sampling technique in qualitative research. The researcher will select the most useful sample for answering the question. The sample can be categorised and themes extrapolated	Useful in qualitative studies. Reflections and relationships between participants are easily traced. Low cost Opens up the potential for further contacts.	The sample may not be representative of the population	(Bryman and Bell, 2007) (Marshall 1996)

Non-probability sample type	Description	Strengths	Weaknesses	Reference
	from. The contacts made in this sample can also act as a useful tool for providing further suitable contacts.			
Quota sampling	In this procedure the sample is again chosen by the researcher specifically to indicate a certain characteristic. The researcher creates categories and then the number of people interviewed in each category is decided upon.	Low cost. There is no need for call backs as those available at the time will be used only. Fast process	Not representative. Judgements are solely made by the interviewer so they are highly interpretive.	(Bryman and Bell, 2007)
Theoretical sample	Takes into account that qualitative study is usually driven by theory. Necessitates the building of theories from an interpretive standpoint from the data collected. Highly suitable to grounded theory	Aids the analysis process as theory is built as data collection occurs.	More suited to grounded theory than other qualitative methods.	(Marshall, 1996) (Glaser and Strauss, 1968) (Acharya et al., 2013)

There is undoubtedly some overlap between the four primary non-probability sampling methods. The choice of method will ultimately be a reflection of the researchers' data collection style and the research questions (Crotty, 1998). It is important to be aware of the purpose of qualitative study during sampling procedures. The primary focus for this research style is the concept of understanding real people in real and natural situations, providing meaning and understanding potential influences (Marshall, 1996). The judgement sample was an appropriate method as it was essential to make judgements on the most relevant people to interview in order for the research questions to be addressed. It has also been suggested that the sample must also be selected in line with the tools used in the research for explaining and understanding the data (Byrne, 2009; Uprichard, 2013).

3.8 Research design: Phase one and two

The data collection procedure was conducted in two stages consisting of a focus group and a series of semi-structured expert interviews. The first stage was carried out as an exploratory focus group with the aim of providing a general outline of construction expert opinions on LCA. The themes and questions posed in this procedure were in line with the literature review findings. Themes were initially developed on thematic trends taken from the literature review and further codes were developed to inform inclusion and exclusion criteria for discussions. An example of the way in which themes were extracted can be found in Table3.7. The thematic concept summary will be explained in more detail in chapter 4.0.

Table 3.7 Thematic concept summary example

Theme	Thematic concepts	Key references
BIM	Technology, collaboration, visual information, communication processes , information exchange, design, building model, multidisciplinary, software, government recommendations	(Hardin, 2011) (Azhar, et al., 2009) (Addor, et al., 2010 (Singh, et al., 2011)

Outcomes from the focus group were used to form the next phase of the study which consisted of semi-structured expert interviews. The focus group aimed to explore and confirm correlations between the literature findings and industry opinion, whilst simultaneously developing the continued line of questioning. The first phase of data collection also aided the development of the research design by informing the participant profile. During the pilot study, it became clear that participants must be selected in a structured manner by using the construction supply chain. Interviews were therefore considered as the most appropriate method for this design. By using interviews individuals from each section of the supply chain could be targeted to ensure a wide selection of experts were identified and included from across the supply chain spectrum.

3.9 Data collection phase 1: Focus group

3.9.1 Focus group

The initial phase for the exploratory work commenced with the extraction of key themes from the literature review. These themes were developed into questions and piloted in the focus group to gauge opinion. It was essential in this research to implement a study which could explore the extant subject area on LCA and low carbon decision making. The focus group was able to highlight the importance of the pre-determined general themes found in the literature; decreasing the subject area to a manageable size. In addition, the use of exploratory studies is supported in social literature; nearly all major studies begin with pilot tests aimed at challenging the feasibility of further research (Thabane et al., 2010). The focus group provided a channel for exploring the potential direction for further data collection.

By pursuing a preliminary qualitative focus group, continuation of the qualitative research approach could be confirmed as the most appropriate design for further study, acting as a qualitative feasibility test (Thabane et al., 2010). Additionally, support for this approach was justified by a lack of scholarly evidence to support qualitative data collection in the area of CO_2 LCA in the construction industry. The focus group was a useful tool for initiating a move towards the analysis of the behavioural impacts of implementation CO_2 emissions calculations. The key challenge was understanding how behaviour controlled by institutional pressures could influence the diffusion of low carbon decision making processes and innovations.

Studies such as Wood and Ellis (2005) and Davis (2008) have advocated their use in construction industry research. These papers have shown some success in establishing outcomes of the wider construction community, perceptions of UK construction relationships and also in establishing criteria to measure construction project success. All of which have been achieved through the use of exploratory studies. Research has also asserted that focus groups are extremely beneficial in gauging opinions and beliefs, whilst simultaneously providing the facilitator and participants with new information which can aid research development (Simon, 1999).

3.9.2 Development of the study sample

The focus group participants were selected based on their industry expertise. A decision was made on the most appropriate people who could provide an insight into the research questions. Potential participants were found through a range of mediums including personal contacts, internet appeals and the sponsoring company. From the focus group, participants were encouraged to provide further contacts who would be interested in taking part in an interview as the research developed. The study sample confirmed that the success of the research was dependent on careful participant selection for the interviews. For the continuation of the research, participants were found from each section of the construction supply chain. Architects, mechanical and electrical engineers, clients, main contractors and sub-contractors were all acknowledged as important actors in the development of supply chain knowledge (see Table 3.7.). Participants were requested in the focus group to express their thoughts on the most influential actors in the supply chain regarding CO_2 emissions. An acknowledgement of the most influential supply chain actors was also requested during the expert interviews which eased the understanding of whose involvement in the study would be imperative.

3.9.3 Focus group: Research design

The focus group discussion panel consisted of a sample of 5 construction industry experts consisting of environmental consultants, building surveyors, and LCA experts. Participants were chosen as authorities in their respective fields and invited to join in focus group discussions via email following university ethical procedure guidelines. Twenty participants were invited, nine agreed to take part with five attending on the day. The final participation figure was close to academic recommendations which state six to twelve participants as the optimum number (Del Rio Roberts, 2011). The focus group was conducted at a neutral location - Manchester Business School on Tuesday 8th October 2013. The session was recorded and then transcribed to facilitate a thematic analysis. Table 3.8 provides a breakdown of the participants involved in the focus group study.

Table 3.8 Breakdown of study participants

Participant	Current role
A1	Chartered surveyor
B1	Environmental consultant
C1	Technical director
D1	Senior sustainability manager
E1	Consultant

The focus group questions and general themes were designed based on the preliminary literature findings. They were chosen to ensure a wide range of technical, behavioural, and data management issues were discussed. These themes were categorised into 8 sections as shown in Table 3.9.

Table 3.9 Themes and questions presented in focus the group

Themes	Specific questions				
Introductory questions	Where are we now with LCA and where have we come from?	What level of progression has there been towards LCA?	Where is the construction industry on its journey to total CO_2 LCA?		
Software	Successes and failures	The role of software	Accuracy Issues	Number of products	
Tools and techniques	BIM	LCA measurement systems			
Sustainability drivers and barriers	Technology	People	Competitive advantage?	External Pressures	
Behavioural issues	Regulation	Incentives	What is the Key impetus for behavioural change?	How does behaviour affect LCA implementation ?	
Construction culture	Is this still a problem? Why?	Cost/quality/time – still most important aspect of a build?			

Themes	Specific questions				
Sectoral collaboration	Is enhanced collaboration required?	Is there a lack of collaboration?	Is collaboration important?	CO_2 assessments using the supply chain?	Short term projects problematic?
Innovation	User = key innovator?	Transitional views of innovation in the construction industry	How successful has innovation been in the past?		

The focus group took the format of a round table discussion and the participants were questioned. Although the focus group had a clear structure, the questions were used as prompts to engage the participants in conversation regarding a specific area of thought. The semi-structured approach to this discursive format aided the development of the expert interview questions as participants focussed on areas of importance.

The initial focus group was carried out with the view to conduct more prior to interviewing individuals to increase the scope of the focus group study. Two further focus groups were organised, however, due to poor attendance rates, primarily due to logistical reasons, these groups were cancelled. An interesting point which was established was that those who were not available to attend focus groups expressed an interest in being personally interviewed. The preference for one to one data collection provided the impetus for the second phase of data collection to move towards one to one interviews as their popularity suggested a more successful way of gathering data. It also raised questions about whether people were comfortable with divulging their opinions on sustainability in a group environment, as most seemed more comfortable with a personal interview style. Although the initial data collection procedure was changed and shortened, the focus group provided a positive starting point for the interviews; indicating key areas of focus within the industry and demonstrating whether initial analysis correlated with the current literature surrounding LCA.

The approach of using a focus group preceding expert interviews held some significant advantages in the development of this research. The focus group enabled the development and testing of initial research ideas. It created a platform on which the literature could be assessed with construction experts whilst providing a base of participants to continue the research. Reasoning behind the use for exploratory studies has been discussed in the literature as a positive preparation for further study, testing the research instrument (Polit et al., 2001; Baker, 1994). The key advantage of this preliminary testing was that any

issues which may be present in the research instrument can be corrected prior to the key data collection phase thus eliminating risk (De Vaus, 1993); a method which proved useful in the development of the interview questions (van Teijlingen and Hundley, 2001). It also informed the method of data collection which would be used for the remainder of the study as focus groups were found to be logistically problematic for continued use. The results of the focus group study indicated that data must be collected in a structured format identifying individuals at each supply chain strata. The strategy of interviewing at each supply chain level was carried forward into the interview stage.

3.9.4 Focus group ethical approval

Prior to the focus group study taking place ethical approval was sought from the University of Liverpool to carry out focus group discussions. Once ethical approval was granted the participants were approached. The participants were contacted by email and were requested to send a signed consent form back in order to take part. The consent form was sent to the participants individually alongside a cover letter explaining interview procedures. Those who contributed remained anonymous throughout the entirety of the research process and were referred to only as letters to ensure that no businesses or identities were revealed. Once the data was collected it was stored securely for participant confidentiality in line with the University of Liverpool ethical procedures.

3.10 The use of interviews

Conversation and the use of dialogue has been the key method of recording human experiences for centuries and is still able to provide insight today (Bolderston, 2012). One of the most extensively used data collection methods in social science is the practice of research interviews (Qu and Dumay 2011). It is thought that approximately ninety percent of all social research uses interviews in some form to enable them to collect data (Briggs 1986; Silverman, 2011). Interviews are considered to be one of the most useful methods of data collection; they enable the researcher to form a connection with the participant. The researcher - participant connection is extremely valuable for gaining useful data because participants are more likely to explore their feelings fully with someone with which they have built a rapport (Houghton et al., 2008; Casey 2004: Kapoulas, 2003). Interviews provide the researcher with human thoughts, feelings, emotions and opinions; none of which can be

provided by the favoured, scientific and statistical approach to data collection (Rowley, 2012).

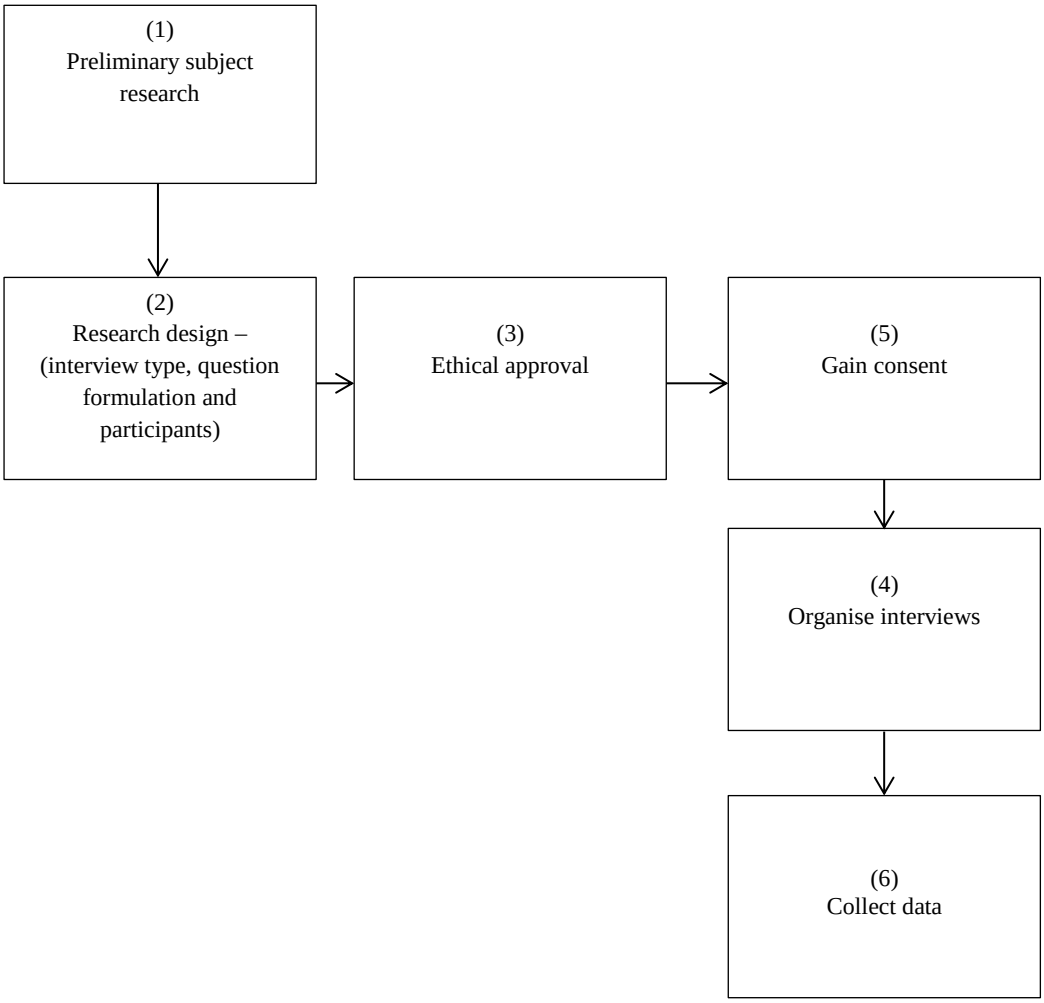
Interviews are highly suitable for the interpretive and phenomenological research as they encourage the collection of rich data sets requiring interpretation (Mack et al., 2005). Findings in interviews are often mutually created due to the interviewer/interviewee relationship (Gray, 2009). When engaging in conversation, the data products are often an interpretation of both the researcher and the researched as questions and answers are interpreted through personal experiences of each individual (Baxter and Babbie, 2003). The rapport between the two individuals encourages a cathartic process to take place inspiring individuals to voice their opinion on a subject (Weiss, 1994; Rosetto, 2014).

Regardless of popularity, the method of interviewing has also come under scrutiny and is particularly criticised by quantitative researchers. They believe that interviewing leads to subjective, interpretive and impressionistic data collection (Denzin and Lincoln, 2000). In order to combat this, it is essential for the researcher to have gained significant background knowledge in the subject area (Rowley, 2012). Additionally, decisions on issues such as interview type, sample, and analysis method must all be in place prior to the interviews taking place (Doyle, 2004).

3.11 Data collection: Phase 2 - expert interviews

The use of interviews in this research was considered appropriate for several reasons. Firstly, the focus group had indicated that specific supply chain participants required targeting, i.e. clients, subcontractor and architects. Secondly, the use of interviews had proven to be successful in previous construction studies such as Kyrö et al (2012). Considerable weight was placed on the importance of providing meaning to the results of this research rather than presenting numerical generalisations. Once the decision was made regarding the use of interviews it was imperative to follow the necessary steps leading to the collection of the data. In this research the interview preparation was broken down into six sections as shown in Figure 3.4.

Figure 3.4 Interview stages



Stage1. Preliminary research: For most qualitative research preliminary work must be carried out prior to data collection. Knowledge is particularly important if the researcher decides upon the use of semi-structured or unstructured interviews as they require the researcher to have background information on the subject. Knowledge is essential for the interview as it has potential to drift beyond the questions asked but is often not as necessary in structured interviews which tend to strictly follow the questions (Rowley, 2012).

Application to this study: The background knowledge for this research was essential in informing the research design; this consisted of conducting a thorough literature review prior to the data collection phase. The literature review covered both technology and human behavioural issues which may inhibit the development of low carbon decision making in the industry. The literature revealed gaps on behavioural implications which may be problematic

for addressing emissions outputs. Current academic work is primarily centred on technology, revealing a research gap in emissions research design.

Stage 2: Research design

To decide upon the most appropriate interview types, the three main interview types were addressed and can be seen in Table 3.10.

Table 3.10 Main interview types

Interview type	Description	Strengths	Weaknesses	References
Structured	Formal and similar to the format of a questionnaire, although much higher contact with the participant occurs. The interviewer. Applicable to neo-positivists who also seek generalizability.	Required questions are answered. Answers are comparable enabling straight-forward analysis	Interview lacks depth as interviews do not stray from the questions.	(Rowley 2012) (Qu and Dumay 2011)
Semi-structured	Semi-formal interview style. Considered to be highly popular. The interviewer is able to answer the desired questions whilst simultaneously allowing the exploration of cultural meaning. It provides both facts and understanding which can be crucial in the process of fully understanding a problem.	High levels of information. Cultural exploration Provides understanding which is key to the analysis	The interview can drift away from subject. Requires skill from the interviewer to regain control if the interview moves away from the desired direction	(Alvesson and Deetz 2000) (Kvale and Brinkmann 2009) Hammersley 2007)
Unstructured	Relaxed and informal interview style. The core of this type of interviewing resides in ethnography. The notion is to provide a situation for the interviewee where they do not feel like they are being interviewed. Conversational approach	Potential to gather large volumes of information which is truly effective of the interviewees experience Used in order to understand the perspective of the interviewee in depth	The interview can drift off subject. The researcher may not gather he required information	(Qu and Dumay 2011) (Hannabus 1996) (Greene 1998).

After assessment of the interview types it was decided that semi-structured interviewing would be the most appropriate method. Semi-structured methods was chosen as it was possible for the interviewer to achieve answers to specific questions, whilst simultaneously enabling the participant to provide meaning and offer reasoning behind their arguments within social context (Kvale and Brinkmann, 2009; Qu and Dumay, 2011). Structured interviewing was disregarded as a discursive approach was considered to be much more

useful to achieving the research aims. Semi-structured methods enable the researcher to have greater control over the interview than unstructured interviewing would allow. If the interview drifts off subject, it is easier for the in interviewer to steer the conversation back on subject.

3.11.1 Interview questions

As explained, questions for the interviews were formulated from both the literature review and the preliminary focus group. The interviews were semi-structured in nature and the themes and questions acted as prompts to cover the most relevant points of the research. Participants were actively encouraged to go beyond the general themes and questions in order to establish issues which were most important to industry experts. Semi-structured interview techniques were chosen as they enabled the most important aspects of the research to be covered, whilst simultaneously enabling the participant to elaborate. The interviewee had the opportunity to offer meaning to their answers explaining why and how an issue may be occurring. It also provides insight into areas of the topic which may have been previously unexplored. A total of 23 interviews were carried out ranging from approximately 20 minutes to over 60 minutes. Most commonly the interviews were conducted face-to-face, however where this was not possible telephone interviews were used. Out of 23 participants just one interview was conducted over the telephone at the interviewee's request. In this case the visual aids were emailed to the participant prior to the interview taking place in order for them to provide answers to the questions requiring the visual aids. The telephone interview was also recorded using specialist recording equipment with the participant's permission and transcribed.

The interview conducted face-to-face were either conducted at the participants' place of work, a university building or a convenient meeting place for the interviewee. Each interview was recorded and transcribed verbatim to enable analysis firstly through thematic coding analysis and secondly by applying institutional pressures to the generated themes. The general themes and questions used in this study can be seen in table 3.11.

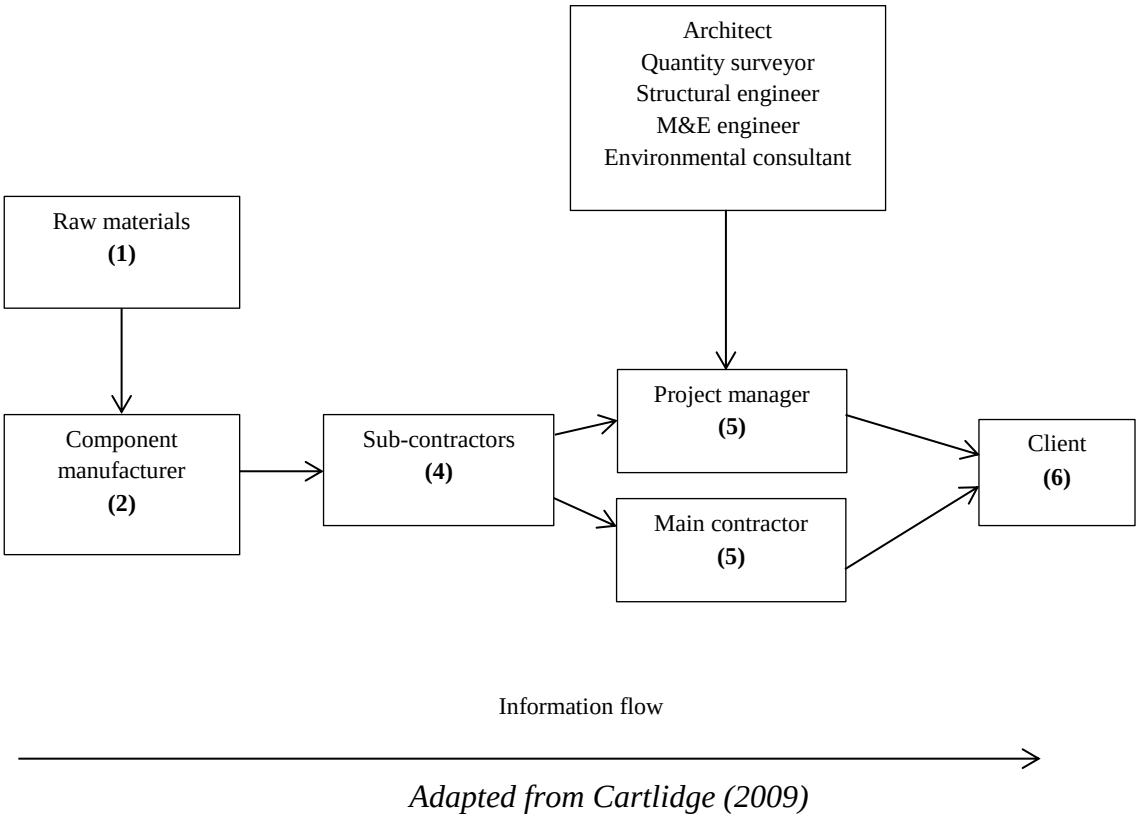
Table 3.11 Interview themes and questions

Themes	General questions				
LCA introduction	Where are we now with LCA?	How important is LCA to the industry?	Where have we come from with LCA?	What level of progression has there been towards LCA in the industry?	Where is the construction industry on the LCA journey?
Software	What do are the key successes and failures of LCA software?	How important is the role of software?	Is comparability between buildings or accuracy more important?		
Building Information Modelling	How important is BIM to the development of sustainability?	Are there benefits to using it with the construction supply chain?			
Sustainability drivers and barriers	What are the key sustainability drivers and barriers in the construction industry?	What are the core incentives for sustainable working?			
Sectoral Collaboration	How important is collaboration in the construction industry?	Is collaboration lacking?	Is enhanced collaboration throughout the construction supply chain required for low carbon decision making?	Is the nature of construction i.e. short term contracts inhibiting the development of LCA systems?	Could external developments i.e. increased business opportunities aid the development of sustainability?- EPDs
Regulation and Legislation	What is the future of legislation and regulation?				
Construction Culture	How influential is construction culture in the development of sustainability?				
Diffusion and construction innovation	Has poor innovation diffusion techniques inhibited the spread of sustainable technology in the industry?	Has previous technology been diffused successfully in the industry?			

Themes	General questions		
The construction supply chain?	Who are the most important supply chain actors in sustainability?	Where do you think are the key influences and decision making relationships?	
LCA stages	At which stage do you think you have the most influence?	At which stages would you like to have most influence?	

The role of the focus group was pivotal in designing the interview questions. After the focus group results had been gathered the importance of the supply chain, and the LCA process became apparent. Therefore two further sections on these aspects of the problem were added during the interview stage in order to assess their impact. Two visual aids were also introduced into the interview process in order to ease the understanding of the questions. Participants were offered a typical construction supply chain diagram (see Figure 3.5) and LCA process diagram (see Figure 3.6) to answer the questions regarding these aspects of construction. Additionally, the position of environmental consultant was added to the design team section of the chain due to a number of consultant interviews. The design stage was thought to be when consultants may have the most input. Interviewees were then asked to mark on the diagrams the key influential relationships, the most important supply chain actors and the stage of the LCA process where they believe that they have the most influence. Where this was not possible on the telephone, the two diagrams were emailed to the participant to use whilst being interviewed and then a request was made for the relevant documents to be returned to ensure continuity throughout the interview process

Figure 3.5 Typical construction supply chain used as a visual aid in interview



Adapted from Cartlidge (2009)

Figure 3.6 Typical LCA process used as visual aid in interviews

3.11.2 The participants

Participants for this study were found through personal contacts, internet appeals, the sponsoring company and through participants. The sample for this research was selected using the judgement sample method. Although there was also evidence of snowball sampling during this research which was evident from the focus group, most candidates were approached for their expertise and supply chain position. The inclusion criterion was simple, yet effective. Participants were chosen based on their knowledge of the area of construction sustainability and their position in the supply chain. The supply chain was broken down into six sections as shown in Figure 3.5. These sections consisted of:

1) Raw Materials
2) Component manufacture
3) Design team
4) Sub-contractors
5) Management
6) Client

It was decided that a selection of participants from each key section would be interviewed in order to address views on construction emissions throughout the supply chain. Interviews were conducted with as many participants from each section as possible; however, raw material extractors and clients were difficult to identify for interviews due to lack of time and or interest. Participants were approached via email or telephone to arrange interview but they either declined or cancelled the interview. Two further interviews were carried out with developers who develop land before construction begins, before the supply chain comes into action. They expressed that they did not believe that they were part of the supply chain per se, but interviewing those involved pre-construction was a useful exercise for understanding whether CO_2 is an issue pre-construction at the development stage. A breakdown of the participants who took part in the interview stage of the research can be seen in Table 13.12 alongside supply chain position as numbered in Figure 3.5.

Table 3.12 Breakdown of interview participants

Participant	Current Role	Supply chain position as per Figure 3.5
A	Lecturer/ Architect	Design (3)
B	Architect	Design (3)
C	Architect	Design (3)
D	Operations director (client for major construction project	Client (6)
E	Group sustainability manager (M&E contractor)	Design (3)
F	Business development manager (Sub-contractor)	Sub-contractor (4)
G	Director - sustainable wooden frame company (Sub-contractor)	Sub-contractor (4)
H	Planning consultant	Management (5)
I	Architect	Design (3)
J	Mechanical design engineer (M&E contractor)	Design (3)
K	Building physics engineer	Design (3)
L	Planning director	Management (5)
M	Technical manager - building physics (M&E contractor)	Design (3)
N	Senior project manager (Main contractor)	Management (5)
O	Technical director (M&E contractor)	Design (3)
P	Architect	Design (3)
Q	Lecturer in building LCA / consultant (industrial background)	Management (5)
R	Environmental consultant	Design (3) and or management (5)
S	Main contractor	Management (5)
T	Main contractor	Management (5)
U	Main contractor	Management (5)
V	Client	Client (6)
W	Architect	Design (3)

Stage 3: Ethical approval

Prior to interviews taking place stage 3 of the interview process was carried out which involved seeking ethical approval from the University of Liverpool in addition to approval granted for the focus group study. Once ethical approval was gained then the interviewees were contacted and interviews were organised. All potential participants were invited to

interview via email or telephone and interviews took place a location of the participant's choice. To comply with the University of Liverpool's ethical regulations no interviews were carried out prior to approval being granted. In addition to this all participants from the interview process remained anonymous and were referred to as a letter i.e. 'participant A'. At no time were the identities of the participants or their associated companies identified in this research. Once the interviews were recorded and transcribed, all collected data was stored securely to protect the confidentiality of interviewees. The final two stages of the interview process (***Stage 5: Gaining consent)*** and (***Stage 6: Collect* data)** could then be carried out. As part of the ethical procedure each interviewee was sent a cover letter explaining the interview process along with a consent form which was signed and returned prior to interview. Once the consent form was received then the final stage, the interview itself could take place.

3.11.3 Ensuring interview success

The three key processes which enable successful interviewing are:

1. Understanding the question
2. Ensuring the flow of conversation
3. Engaging the interviewee

These processes are supported in interview literature (Doyle, 2004; Rowley 2012; Qu and Dumay, 2011). One of the most important aspects of the research design was making sure that the interviewee fully understood the questions being asked. Careful consideration was given to the wording of the question, only questions which required extensive responses were asked, nothing which may be deemed sensitive was included in the questioning and no leading questions were used. All of which are considered essential for legitimate interviewing practices (Rowley, 2012). The importance of this was found during the interview process as it became evident that certain words were interpreted differently. The word 'incentive' for example was taken in different contexts in the interviews. In some cases it became apparent that this particular word was not understood in the intended context.

The second critical aspect of interviewing is the importance of keeping a good conversational flow throughout the interviewing process (Kvale and Brinkmann, 2009). Making sure this was possible during the data collection process required extensive background knowledge on the subject area which was provided by the literature review. It became apparent throughout the interview process that the knowledge of the interviewee varied and sometimes, it was

essential to interject and encourage greater elaboration on a particular point, a method which was slightly more difficult to carry out during telephone interviews when body language was not aiding the communicative process. The conversational flow on the interviews was relatively easy to maintain as generally once the participant had discussed a certain aspect of the question the conversation naturally flowed into unexplored areas. Active dialogue between the interviewer and the interviewee was one of the key reasons why this type of interviewing was an appropriate choice for this research. Not only did it enable the participants to answer the key questions posed, but also provided meaning, revelling previously unexplored considerations of carbon calculation methods.

The final issue which was essential in ensuring the interview process was successful was maintaining interviewee engagement. In some cases if those involved in the process lose interest in the questioning, or lack interest in the subject then the interview can be short, and potentially provide inaccurate data. A vital part of the research design is understanding who needs to be interviewed to achieve the research goals (Rowley, 2012). In the case of this research participants were chosen based on their knowledge of the subject and their position in the construction supply chain. By assessing these two aspects of an individual a decision could be made on their suitability for participation in the study. Knowledge of LCA and sustainability issues meant that the participant would able to comment on those aspects of construction. By interviewing at each section of the supply chain individuals were able to comment on the perceived impact that their supply chain position has on low carbon decision making.

Acknowledging which supply chain positions had key impacts within the low carbon decision making process aided the understanding of why low carbon decision technologies are not currently working in the construction industry. Interviewing those who understood the concept of LCA but perhaps held negative views on the subject was also useful for creating a depth to the research and increasing validity. The interviews were not solely concentrated on those who held enthusiasm for sustainability. Surprisingly this did not detract from the success of the interviews as those who disregarded emissions in the industry did so with vigour and held strong views. Therefore the interviews conducted flowed with ease, projecting a cathartic process and highlighting distrust of the reasons behind lowing emissions (Weiss, 1994; Rosetto, 2014).

3.11.4 Addressing interview problems

Despite the generous perceived benefits of interviewing this method of data collection has also come under scrutiny. The main interview challenges are explored in sections 3.11.4.1 - 3.11.4.3.

3.11.4.1 Idealised and impressionistic interviewing

Semi-structured interviewing has been labelled as idealised and impressionistic in nature which can have negative impacts on the perceived reliability and validity of a piece of research (Denzin and Lincoln, 2000). The participant researcher relationship can also have an effect of the outcome (Qu and Dumay, 2011). In order to overcome this challenge the focus group and the interviews were carried out in a professional manner. Only two previous participants were known prior to the interview taking place to ensure that relationship between interviewer and interviewee did not impact on the findings.

3.11.4.2. Researcher assumptions

A further issue encountered with the use of interviews is the assumptions of the researcher. The researcher will presume that interviewees are competent individuals and truthful in their analysis of the situation (Alvesson, 2003). Some have dismissed interviews due to this problem as it is seen as an imbalance of power (Qu and Dumay, 2011). There is no way of fully knowing whether the interviewee is competent or trustworthy; however the judgement of the researcher is important in this instance. Participants will be selected based on theoretical appropriateness for inclusion in the study. In a subject devoid of emotional attachment, in neutral environments with no repercussions due to anonymity, it is unlikely that there would be any benefit for interviewees being dishonest or untruthful.

3.11.4.3 Understanding

A further problem which comes to the fore with interviewing is the sense of understanding between the interviewer and the interviewee. Questions can be interpreted differently by people as their world views may contrast. Evidence of the associated problems with understanding was acknowledged with the word ‘incentive’ as previously discussed. The two most common critiques of an interview methodology is firstly language and secondly the researcher and participant relationship (Qu and Dumay, 2011). There is an argument that

language itself actually constructs reality rather than mirroring it thus it becomes difficult to assess fact from fiction (Alvesson, 2003).

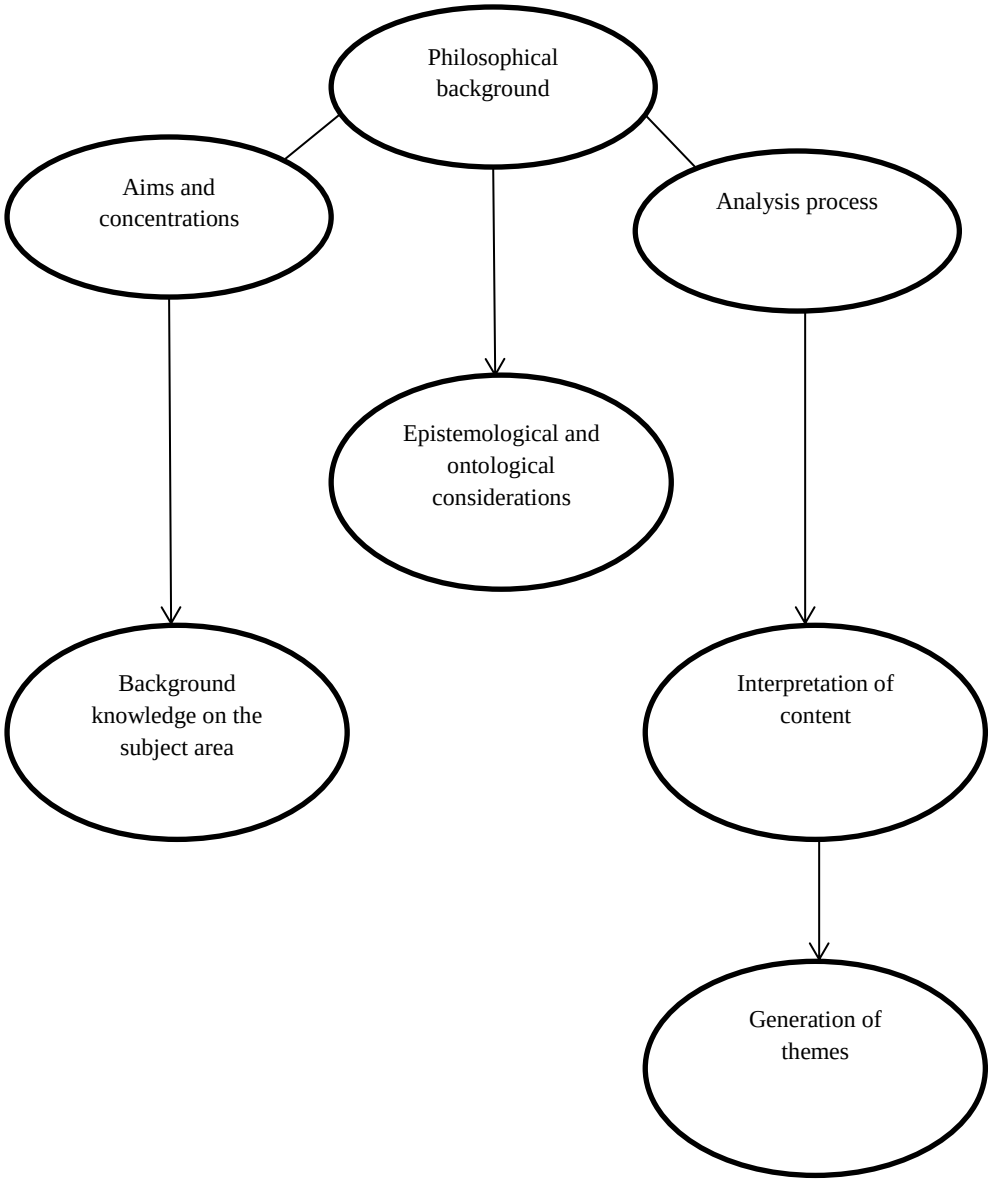
3.12 Data analysis

The analysis of data can be fraught with issues regarding decisions on appropriate methods. The chosen analysis method must ensure that the collected data can be used to obtain answers to the research questions. Many different approaches have been considered in the literature as qualitative enquiry has gained significant popularity (Bryman and Burgess, 1995; Miles and Huberman, 1994; Silverman, 1993; Strauss, 1987; Jensen, 1991; Marshall and Rossman, 1995). The growing acknowledgement of the usefulness of qualitative examination has been hailed as a progressive and necessary step towards understanding deep and complex social interaction (Attride-stirling, 2001). Although the method is receiving welcomed attention, literature is still lacking on how to analyse the material which the qualitative researcher acquires (Bryman and Burgess, 1994; Silverman, 1993). In view of this, tools for analysing qualitative data are coming to the fore, examples of which are frameworks and thematic networks (Attride-stirling, 2001; Ritchie and Spencer, 1994; Smith and Firth, 2011). It has been acknowledged that one of the most difficult aspects of qualitative analysis is ultimately bringing together narratives to provide meaning (Dibley, 2011). Qualitative research requires an understanding to occur between the researched and the researcher, as the data produced is mutual and contextual (Lincoln and Guba, 1985; Graneheim and Lundman, 2003). A systematic and structured method for the analysis of such data can be extremely beneficial in explaining meaning.

To aid analysis the theoretical substance of the study was also taken into account when participants were chosen. The theoretical lenses used to understand phenomena in this study were DiMaggio and Powell's (1983) institutional theory and diffusion theory (Rogers, 1971). These theories were also noted for the data collection process, for example, the importance put on communication in diffusion theory aided the development of the questions asked regarding collaboration. Whilst selecting participants, the relationships between members of the supply chain became clear and this was only possible by ensuring that the relevant collaborative partners in the supply chain were identified and questioned. Acknowledgement of the theoretical standpoints also helped in the analysis process. The analytical approach of the research is often a reflection of the researcher's epistemological and ontological assumptions (DiGaetano and Waksbeg, 2002; Uprichard, 2013).

In this research a thematic content analysis was used via a systematic approach and additionally the research was cross referenced and analysed via the two theoretical lenses. Content analysis is renowned for being a highly flexible method. It can range from being impressionistic and interpretive through to being highly systematic in nature (Hsieh and Shannon, 2005). The standard for this method in its most basic form is simply to categorise raw data into codes (Elo and Kyngas, 2008). Qualitative data which is systematically coded is more likely to be guided by the research questions, subject and the data (Fingeld-connett, 2013). Qualitative analysis is also heavily shaped by the research approach and whether it is deductive or inductive (Elo and Kyngas, 2008). The deductive approach of this research largely informed the way in which the data was analysed. Prior knowledge of the subject area gained through the literature review was the initial step which provided potential themes and codes in a top down a priori approach. These codes provided the search themes in the data. Having prior conceptions of codes was also a distinct benefit of the accompanying focus group. An understanding of potential themes provided a framework of possible codes which could be changed at any time. The ability to change codes enabled the testing, adaptation and expansion of theories whilst simultaneously improving the validity and relevance of the generated themes (Zimmer, 2006). The main characteristics of thematic content analysis from the background preparation through to the interpretation of the thematic findings can be seen in Figure 3.7.

Figure 3.7 Main characteristics of thematic content analysis



(Vaismoradi et al, 2013)

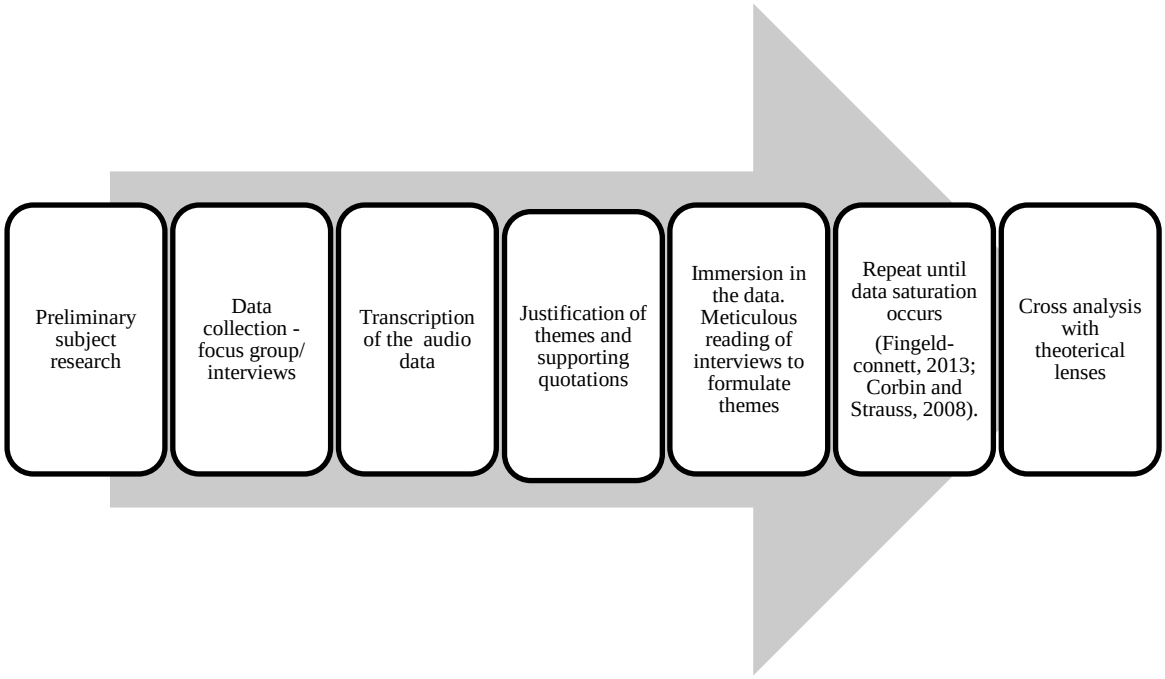
The generation of themes via the analysis of the data content is a highly popular characteristic of qualitative research widely used in the analysis of results (Smith and Firth, 2011). The interpretive nature of thematic methods provides highly illuminating and rich analyses of human based investigations and the development of theories (Tesch, 1990). The literature shortfall on insight into the human behavioural phenomena associated with carbon

calculation and low carbon decision making in construction, provided the foundation for a necessary and distinctive contribution to the field. By using thematic coding, rich insights into this phenomenon could be established. It enabled the research to address the complexity of the associated human behavioural issues with construction emissions. The thematic coding method is also applicable to many epistemological approaches which enable testing and expansion on popular theories (Braun and Clarke, 2006).

3.13 The analysis process

As previously explained interviews were conducted face to face or in some cases via telephone, however, one commonality between all interviews was that each interview was recorded. The recordings were then transcribed verbatim. Once all interviews had been transcribed they were printed so that they could then be analysed using thematic analysis. Each transcript was highly scrutinised to develop codes, a process whereby each line of the transcription was meticulously considered. With the initial thematic concept formulation developed from the literature, the establishment of appropriate codes for the data had a starting point prior to data collection. These codes were developed by analysing the frequency of the most commonly occurring themes. The process by which the data was analysed was in line with the common principles of qualitative investigation. Namely, the immersion of the researcher in the data in order to understand the collected information and its application to the investigative phenomena, and formulation of a data coding system through thematic selection and understanding the links between codes in order to establish theory (Morse and Richards, 2002; Smith and Firth, 2011). An outline of the stages carried out in this investigation can be seen in Figure 3.8.

Figure 3.8 Key data analysis stages



Themes for the focus group were established via the thematic framework produced from the literature review (see Table 3.7). The frequencies of thematic concepts were checked, supporting quotations were provided as evidence and the participant was listed. The procedure enabled a strong thematic analysis to take place, providing the grounding for the in depth analysis in the discussion. The coding matrix is shown in Table 3.13 and an example of the final focus group data presentation is shown in figure 3.14.

The interview data was also coded and evaluated using the same thematic framework. Table 3.15 highlights how the interview data was then analysed using institution theory as a theoretical lens for analysis adapted from Bhakoo and Choi, (2013). It highlights the core indicators which were used to assign isomorphic pressures to the thematic data. The final presentation of the results is shown in Figure 3.15. Thematic data was given an isomorphic category to aid the understanding of how isomorphic pressure aids or inhibits the diffusion of low carbon innovation.

Table 3.13 Focus group and interview coding matrix (example)

Coding theme	Recurrence	Supporting quotations	Participant
Building Information Modelling (BIM)	78	'The BIM model is having…that level of …visual information' (to make low carbon decisions) 'BIM is going to be a huge driver for the whole lifecycle of a building'	A A

Table 3.14 Focus group data presentation (example)

Theme	Participant supporting quotes
BIM	'I think that's going to be the huge drive…looking at the wider picture' 'That level of…visual information' 'The driver for lifecycle going forward' 'They are using it effectively in collaborative work'

Table 3.15 Institutional pressure coding matrix for interviews (example)

Description	Coding Category
Comments about pressures to conform to social norms	Normative pressures
Comments about professional systems i.e. supply chain structures, contracts etc.	
Comments about social values in order to appear legitimate	
Comments about negative impacts of normative pressure i.e. limited collaboration as a social norm	
Comments about positive application of normative pressure i.e. potential for institutionalising sustainability, ensuring that it becomes common practice	
Comments about established construction strategies	
Comments about enforcing compliance with sustainability schemes	Coercive pressures
Comments about the impact of cost/ budgets/finance	
Comments about contractual obligations in construction projects i.e. design-build	
Comments about government enforcement i.e. BIM implementation by 2016	
Comments about power i.e. - supply chain, client	
Comments about influence –driven by power	
Comments about external regulation	
Comments about legislation i.e. Climate Change Act 2008	
Comments about pressure to conform by viewing others' actions	Mimetic pressures
Comments about the generation of communication channels via mimesis	
Comments about uncertainty/ risk reduction	
Comments about viewing success	
Comments on influence driven by the fear of appearing illegitimate	

(Adapted from Bhakoo and Choi, 2013)

Table 3.16 Expert interviews – final data presentation example

Theme	Participant supporting quotation	Isomorphic category
Supply chain Integration	I think there's a lot of good work going on. A lot of people are pushing forward with it and there's a lot of unity between different sectors in trying to get agreement on that work.'	M, N
	'At an early stage you don't know the full make-up of the building, and so therefore you don't do the analysis and you wait until the end of the building, when it's completed, then you go, there's my analysis, at which point it's too late to actually change anything, and so I think there needs to be shift in to a design stage tool'	N
	'Separation of duties actually can make it harder to design an environmental building because you've got to get more people on board to agree with that policy. If there's fewer people and they all agree it'll go ahead. If there's a larger group and most agree but one disagrees, you still might not go forward with the solution to get a much more environmental building at the cost of, say, 1% extra of the building, because their remit is to make sure that the cost doesn't overrun, which isn't actually what should be looked at, because they're not looking at the whole lifecycle, they're looking at an immediate'	N

The approach taken to conduct this research meant that a systematic review of the interview transcripts was required. A systematic approach enabled testing of the generated theories and preconceived notions about the research outcomes, which were formulated from the prior knowledge gathered from the literature review. It also enabled the research to remain in line with the epistemological assumptions (Vaismoradi et al., 2013). Due to the volume of data and the complexity of the subject area there was a clear need for a structured thematic review to ensure that no important data was missed.

The purposive sampling method used meant that data was collected with a number of participants in mind. For example, the notion was to interview at each stage of the supply chain, therefore there was an expectation to interview around three participants from each section of the supply chain. When carrying out qualitative research, the findings are gauged based on data saturation. It is argued that data saturation occurs when new data does not enhance the findings (Fingeld-Connett, 2013; Corbin and Strauss, 2008). Saturation is considered to occur at the point when multiple investigations have been carried out as there is no defined number for data saturation (Francis et al., 2010). As a purposive sample was used to acquire data from different supply chain actors, more participants could have been interviewed, and would have been, however at the end of the data collection cycle there was a realisation that the data saturation point had been reached. Data collection was deemed to be complete after an exploratory focus group study and twenty three interviews had taken place.

Both data collection methods collectively produced approximately twenty four hours of recorded data which produced 160,000 words of transcribed audio discussion. At this point no new themes or findings were arising in the data and so therefore it was felt that that the data collection cycle was complete.

3.14 Chapter summary

The aim of this chapter was to discuss the research methodology used in this study alongside the research methods. Particular emphasis has been placed on the theoretical concepts which ground the research and how these have informed the research design. The ontological and epistemological standpoints have been assessed to enable an understanding of the paradigm used. The qualitative method of data collection has been explored and justified alongside the design and discussion of both phases of the research. Finally the methods used for data analysis have been addressed to provide understanding of how the data was coded to provide grounding for the presentation of the findings in chapter 4.0.

Chapter 4.0 – Findings

4.1 Introduction

The examination of the results was carried out firstly by conducting a content analysis of the collected data. The data from the interviews was then investigated further through the application of management theory. Firstly, DiMaggio and Powell's (1983) institutional theory was used to understand how institutional pressures may encourage or inhibit the development of CO_2 emissions analysis in construction. Secondly the interview findings were then considered using diffusion theory (Rogers, 1971), with a specific focus on the supply chain. Diffusion theory was used to explain the potential for the uptake of new work strategies or technologies which could ease emissions assessment in the construction industry.

The data collection phase was guided by data saturation; the point at which no new information was occurring and/or providing weight to the findings (Glaser and Strauss, 1967). A total of 24 hours of recorded data was collected, equating to 400 pages of verbatim transcriptions and approximately 160,000 words. After gathering this data it was concluded that further interviewing would not enhance the findings (Fingeld-Connett, 2013; Corbin and Straus, 2008). Chapter 4.0 will present the findings of the research in two parts. Phase one will outline the focus group findings and phase two will address the interview findings. The main body of the interview data will undergo two analysis processes, namely content analysis and theoretical analysis.

4.2 The research questions

The research questions consider the diffusion of low carbon decision making throughout the construction industry, environmental business legitimacy and the impetus for construction companies to take on low carbon decision making innovations. To recap, the research questions for this study are as follows;

RQ1. *How can low carbon decision making strategies diffuse throughout the construction supply chain?*

RQ2. *How can low carbon decision making strategies improve a firm's legitimacy in the construction industry?*

RQ3. *What provides the impetus for construction companies to take on low carbon decision making innovations?*

The proceeding sections of this chapter explore and present the results from the data collection phase of the research.

4.3 Phase one – focus group findings

Themes were deduced via assessment of the literature which enabled the establishment of potential themes prior to the data collection taking place. Table 4.1 highlights how these themes were formed. The initial theme formation based on literature acted as an aid for the development of themes in the focus group. It also provided an indication regarding the complexity of potential solutions to the CO_2 emissions problem in the construction industry with many of the themes overlapping despite their apparent differences.

Table 4.1 Summary of key literature themes

Theme	Thematic concepts	Key references
BIM	Technology, collaboration, visual information, communication processes , information exchange, design, building model, multidisciplinary, software, government recommendations.	(Hardin, 2011) (Azhar, et al., 2009) (Addor, et al., 2010 (Singh, et al., 2011)
Supply chain engagement and Integration	Inter-firm collaboration, green supply chains, data sharing, relationships, influence, networks, communication, information sharing, cohesion, efficiency, cooperation, customer focus, competition, structure, sectoral influence.	(Beamon, 1998) (Cheng, et al., 2001) (Love, et al., 2004) (McCormack and Johnson, 2001) (Vaidyanathan and Howell, 2007)
Collaboration	Influence, communication, relationships, integration, cohesion, conflict, flexibility, information sharing, team work, participation, data sharing, lack of collaboration regarding sustainability.	(Dainty et al., 2001) (Briscoe and Dainty, 2005) (Bal et al. 2013) (Coelho and Novaes, 2008) (Andrade and Ruschel, 2009) (Persson and Orlander, 2004)
Training and education	Implementation of new processes require training, implementation barriers, new working systems, technology, knowledge and understanding.	(Janda, 2011) (Akintoye et al., 2000)
Behavioural change	Small changes to encourage greater changes, new work strategies, enhanced information.	(Male and Stocks, 1991) (Janda, 2011)
Software and technology	Technology, methodology, methodological differences, scope and boundary issues, technological literature focus, firm centric software, too much focus on technological solution.	(Chevalier et al., 2010) (Pieragostini, et al., 2012) (Hischier, 2011) (Koh et al., 2013) (Erlandsson and Borg, 2003)

Theme	Thematic concepts	Key references
The client	Power roles, key decision maker, responsibility, traditional structures, finance, influence, primary innovator.	(Ahmed and Kangari, 1995) (Ryd, 2014)
Cost	Cost minimisation, supply chain selection, key decision making factor, cost quality, time.	(Sheu et al., 2005) (Rodriguez-Melo and Mansouri, 2011) (Hart, 1995) (Abanda et al., 2013)

The content analysis of the data collected in the focus group supported themes found in the literature review, confirming that the direction of the study was in line with perceived under-researched areas in the literature. The coding matrix displayed in Table 4.2 highlights how codes and themes were extrapolated via the use of references, phrases and supporting quotations. Participants were labelled as per Table 3.8 using participant job titles. It is this process which enabled the key themes to be established and investigated.

Table 4.2 Thematic coding matrix for focus group

Theme	Participant supporting quotes & participant (as per Table 3.8)
BIM	'I think that's going to be the huge drive…looking at the wider picture.' (Participant A1) 'That level of…visual information.' (Participant A1) 'The driver for lifecycle going forward.' (Participant C1) 'They are using it effectively in collaborative work.' (Participant A1) 'BIM is going to revolutionise the industry.' (Participant C1) 'The Governments have said by 2016 all projects will be BIM level 2 as a minimum for Government related jobs.' (Participant C1) 'The focus around BIM, amongst BIM users, is around the technology and the software.' (Participant E1) 'We still continue to focus on technology' and I think as an industry we need to focus on collaborative working.' (Participant E1)
Supply chain engagement and integration	'You've got to look back…to the manufacturers in terms of what information they are providing.' (Participant A1) 'If you get primary data from your supply chain, you can go in and change it.' (Participant E1) 'It's having flexibility and reliability.' [of information] (Participant C1) 'The RIBA plan of work…encourages the designers to engage with stakeholders.' (Participant C1) [Carbons are lower] 'If I've got my supply chain closer to the project, which is the localism issue.' (Participant E1) There's a blockage for wider knowledge because that's why we've gone down the simple route, we use secondary data, we engage the supply chain.' (Participant C1)

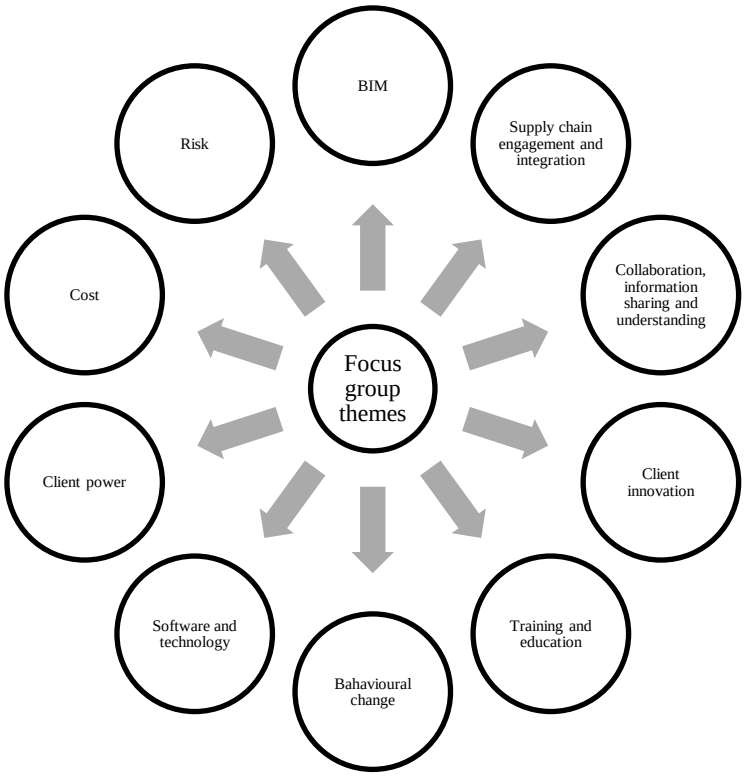
Theme	Participant supporting quotes & participant (as per Table 3.8)
Collaboration, information sharing and understanding	'Knowledge…understanding…I think that's absolutely key.' (Participant E1) 'We don't know the everything and anything…so it's that level of information which you have available.' (Participant A1) 'We are just not talking to each other.' (Participant C1) 'We still continue to focus on technology and I think as an industry we need to focus on collaborative working.' (Participant C1) 'Collaborative working is key.' (Participant E1) 'Working together…the business isn't used to doing that…used to working in its own little silo and trying to break that down is quite difficult.' (Participant C1)
Client Innovation	'It [innovation] depends where you are in the chain.' (Participant E1) 'Innovation doesn't have to be the grand new…something which is going to change the world, just something which is different.' [Only the client has the ultimate power to do this] (Participant C1) 'Different clients approach it differently.' (Participant D1) 'There's a perception that green [innovation] costs more.' (Participant E1)
Training and education	'Training and awareness is incredibly important.' (Participant C1) 'Within two months after the training they were coming back with questions, can we change this, what happens if we do this, and it was actually engrained within a year.' (Participant C1) 'It effectively doesn't cost them anything to join the BIM, other than training awareness.' (Participant A1) 'I've sat there for so many training sessions and I go home, speak to the Mrs, I don't know what that was all about, you know, because it's so complex, it's so technically complex.'(Participant C1) 'See my problem is, we're all looking at the same problem, which is global warming, carbon education.' (Participant C1) 'Training's important. I think … maybe a year, two years ago, within [insert company] we were talking sustainability, now a lot of people get what sustainability is.' (Participant D1) 'I think we've also … it's bad education, it's about changing peoples' views and letting people understand what it is that you know us designers are trying to…' (Participant E1)
Behavioural change	'I think it's very much a behavioural change.' (Participant A1) 'How we learn to make the building work more passively, how we reduce our running costs, how we turn things off, so you know, in small homes, it's reasonably easy to do.' (Participant C1) 'So I think there's more behavioural training at that level of the industry.' (Participant A1) 'The case that is I mentioned in the States, have a fascinating tenant agreement, so you might pay a slight premium for renting a property with a … but then all your water, all your energy, is free, up to a certain point. If you go over that point you really get clobbered. So that sort of forcing behavioural change within the users as well.' (Participant E1) 'Legislation will take it so far, because then it is behaviour.' (Participant E1) 'The trend is to switch those around now so, if you take the lift, you know, it's boring, they pipe horrible music at you. You take the staircase, you can walk up and you get the views. It is behavioural.' (Participant E1)
Software and technology	'Well I think ultimately I think one of the issues is from a designer's point of view actually, there's a raft of different umm sort of … products out there, particularly with the umm … say Greenwash or Green-bling sort of thing.' (Participant A1)

Theme	Participant supporting quotes & participant (as per Table 3.8)
	Well we use IES as an industry standard and the reason we use that because it's an AutoDesk product and we can import it, you know, there are 101 out there, lots of different ones.' (Participant C1) 'The problems you have with carbon is there's that many different data sets out there, different tools out there, which is the right one to use, if you use a different data set you come up with a different answer, if you use a different scope and boundary you get a different answer, these are issues that are fundamentally difficult to overcome.' (Participant E1) 'I've got an argument that says there is no more energy saving to be made at the moment. Technology is where it is. It's all about optimisation now for me.' (Participant C1) 'We need … we had the industrial revolution to kick us all off didn't we. Now we need a technology revolution.' (Participant C1)
Client power	'It's very much … enlightening the client…the better understanding you have as a client, in terms of sustainability, and …promoting that, then it effectively …goes down the chain.' (Participant A1) 'It depends what the drivers are in terms of you know whether it be cost or sustainability.' (Participant A1) 'The [insert company] said we want one, there you go, they want one, they can have one.' (Participant C1) 'They're not having anything super risky market because the market want what the market want.' (Participant C1) 'They were adamant on having slate from China. You look at the embodied carbon on that. Crazy. You know we just get the green guide out and say do you really think you want to get that from there, this is the green guide … no, no, you want that black, looks awful, but that's what they wanted, and they're paying the bill.' (Participant C1) 'If I've got my supply chain closer to the project, my carbon's are lower, yes, the client's happy.' (Participant E1) 'The RIBA overlay actually is structured to advise the client to bring the FM provider to stage one.' (Participant C1)
Cost	'It depends what the drivers are in terms of you know whether it be cost or sustainability.' (Participant A1) 'Obviously looking at the cost side, purely the costs, you know, discount and everything else, then that's a different obviously issue.' (Participant A1) 'Yes, well I think in terms of … it's an interesting thing because I mean to say CO_2 and to say cost savings you know although it can be you know the same thing in essence, you know, it depends who you are speaking to.' (Participant D1) 'Everybody's just looking for the cheapest option..' (Participant E1) [Carbon calculation] 'Very expensive and onerous, it's not good for SME's.' (Participant C1) '£70K in BIM training full stop. That's what it cost us. Never going to get that back in a month of Sunday's, but we said it's a business decision.' (Participant C1) 'But then, if you look at the SME levels, it effectively doesn't cost them anything to join the BIM, other than training awareness. The perception I need to go out and buy all that stuff, but they don't.' [It's about collaborative working] (Participant C1) 'lifecycle analysis has a capital cost depreciation going all the way down, you know, like I.T., it's out of date in five years.'(Participant C1)

Theme	Participant supporting quotes & participant (as per Table 3.8)
	‘Its got a climate wall on it. Cost an absolute fortune.’ (Participant C1) ‘We still have them but they've been hijacked by getting the lowest cost, rather than getting fit for purpose.’ (Participant C1) ‘Surveys weren't done before then, and [BIM]‘There's only 15% uptake in the industry at the moment.’ [because] (Participant C1) ‘It's cost.’ (Participant C1) ‘You don't reduce carbon just for the sake of cost, you want to save carbon. We find that also by commercialising Green [company] as well, so the focus is now looking at carbon and reducing cost also.’ (Participant D1) ‘We saved about 20% cost. So it influenced the client to always want to be green and do the right thing.’ (Participant D1) ‘Yes, you're right on the cost issue umm … there are many in the UK willing to pay that premium. I think we're starting to see it.’ (Participant E1)
Risk	‘They’re not having anything super risky…nobody wants to be the guinea pig, unless they want it.’ (Participant C1) ‘The issue is library ownership.’ (BIM Data) (Participant C1) ‘There’s lots of interesting things going on in the world of collaboration like integrated project insurance.’ [sharing risk and reward] (Participant E1)

The coding matrix shown in Table 4.2, alongside the literature findings shown in Table 4.1 highlight how the thematic codes were formulated indicating key concepts and quotations which led to the generation of themes as displayed in figure 4.1.

Figure 4.1 Key focus group themes



The focus group themes were in line with the human behavioural gaps found in the literature in areas such as collaboration, supply chain engagement, behavioural change and client power (Andrade and Ruchel, 2009; Vaidyanathan and Howell, 2007; Janda, 2011). The content analysis showed that between industry experts there is a clear understanding of the need for a more holistic approach to LCA. There was a perceived emphasis on predominantly human behavioural centred aspects of carbon calculation; however the infiltration of technology underpinned the entire process, highlighted by the frequency of themes shown in Figure 4.2.

Figure 4.2 Theme frequencies – focus group

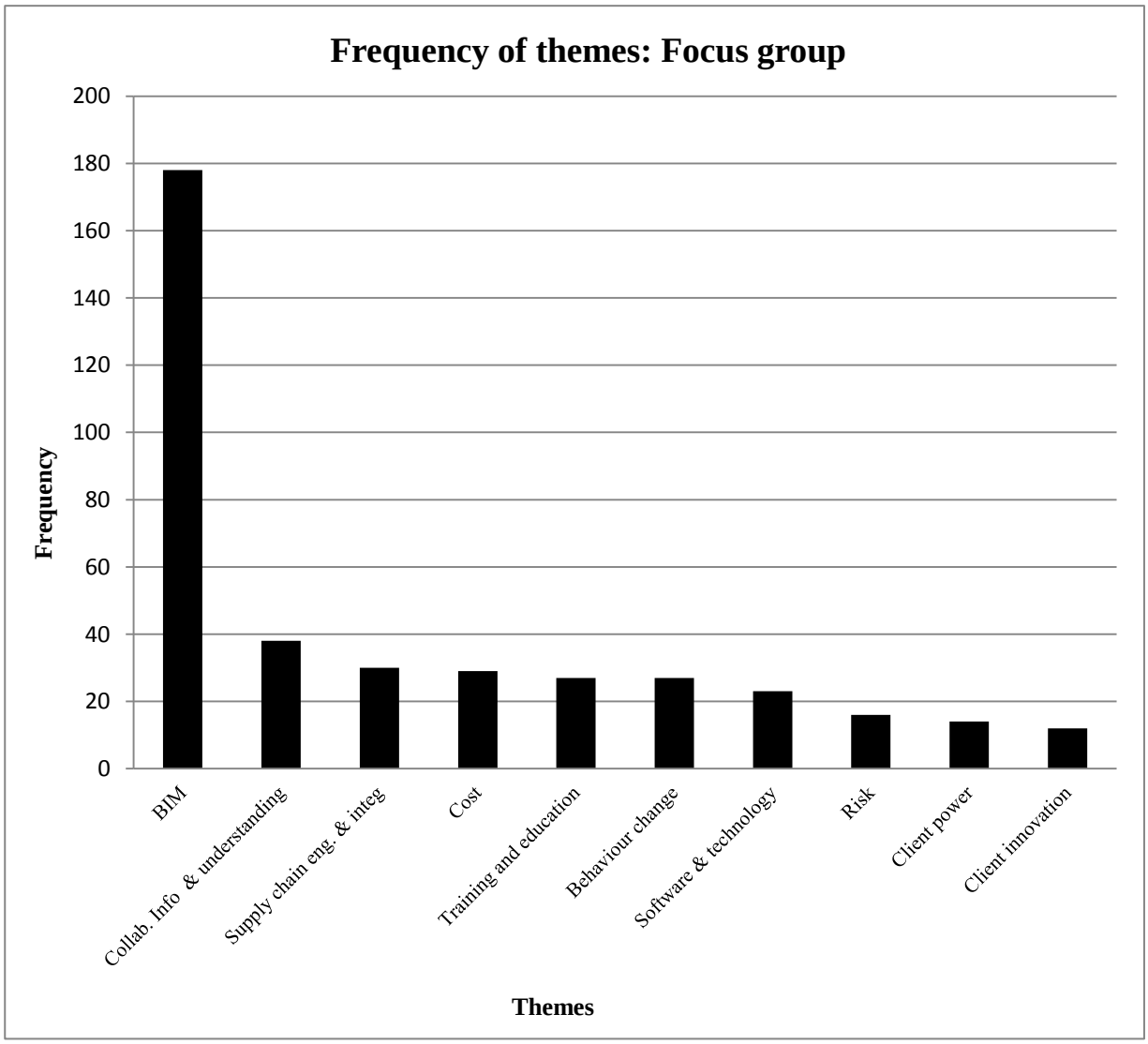


Figure 4.2 shows emphasis was placed on Building Information Modelling (BIM) throughout the focus group discussions. BIM's prominence also provided a requirement for its inclusion in the subsequent interview questions. The use of BIM, based on the frequency of the references made to the technology was around 45 percent of the total discussion. It was followed by collaboration, information sharing and understanding (10 percent). Supply chain collaboration and integration held 8 percent of the total discussion time. Cost, training and education and behaviour change held around 18 percent of the conversation with the remaining discussions covering software and technology, risk, client power and client innovation (27 percent) collectively. The focus group enabled an understanding of the areas of key importance in the construction industry prior to committing to further data collection. The findings indicated a focus on technology but with an underlying acceptance of human behavioural importance such as collaboration. An interesting finding in the results was considered to be the emphasis on client power which appeared to be an important factor in the sustainability of a building, supported by the following quotations:

> *'Its got a climate wall on it. Cost an absolute fortune. The [insert company] said we want one, there you go, they want one, you can have one.' (Participant C1)*
>
> *'It's very much… enlightening the client…The better understanding you have as a client, in terms of sustainability…It goes down the chain.' (Participant A1)*
>
> *'We built the headquarters building round there and they were adamant on having slate from China. You look at the embodied carbon on that. Crazy. You know we just get the green guide out and say do you really think you want to get that from there, this is the green guide … no, no, you want that black, looks awful, but that's what they wanted, and they're paying the bill.' (Participant C1)*

The focus group presented an overview of the key themes applicable to the industry which should be included, providing a framework of potential relevant themes in order to ensure that the research questions could be addressed. The focus group findings assimilated the need for research on the behavioural implications associated with low carbon decision making in construction. Despite an underlying thirst for a technological solution there was also a drive for a modification in working strategy via increased integration and behavioural changes underpinning the focus group findings. The changes made to the interview questions as a result of the focus group were minimal but essential to the development of the research. Five new areas of questioning were added to ensure that all key human behavioural areas were included; one further section (tools and techniques) was removed as this was likely to be

covered in other lines of questioning associated with the discussions on Building Information Modelling. The new questions and reasoning behind their inclusion can be seen in Table 4.3.

Table 4.3 New questions based on focus group findings

Question theme	Reason for inclusion
Building Information Modelling	Due to the importance of BIM in the focus group a separate section was added for discussion in the interviews. Although a 'software' section remained it did not fully cover specific software and as BIM was deemed to be the most important, its inclusion was essential.
Regulation and legislation	It was considered important to include this section to understand the potential influence that regulation and legislation has on carbon emissions. Currently emissions regulation exists as a guide only and it was useful to understand where the industry expects legislation to move forward and its potential impact on the future of carbon emissions.
Diffusion and construction innovation	It became clear from the focus group data that there had been a considerably low uptake of LCA products. Therefore in order to understand how any solutions to rising emissions could be successful throughout the industry, it was important to understand how innovation could be diffused correctly for widespread uptake.
The construction supply chain	The supply chain was a critical component for this research and was confirmed in the focus group. Widespread engagement from suppliers through to the client was deemed essential in the dissemination of carbon data and low carbon decision making strategy and education.
LCA stages	The LCA stages section was added in line with the supply chain. It was included to examine the stages at which each section of the supply chain felt that they had the most influence over emissions. Acknowledgement of the stages enabled the researcher to assess the implementation of a low carbon strategy via supply chain impacts.

Further findings from the focus group showed how interconnected the themes were and how potential barriers to sustainable working may be interrelated. Interconnection between themes highlighted the complexity of low carbon decision making. The acknowledgement of complexity was useful for understanding how one issue could be dealt with by implementing a solution for another. The connections between themes can be seen in Table 4.4.

Table 4.4 Interconnection of focus group themes

Key Theme	Theme connections
Client power	• Client innovation • Behaviour change • Training and education
Cost	• Training and education • Risk • BIM • Behaviour change
BIM	• Supply chain engagement and integration • Collaboration information sharing and understanding • Software and technology • Risk
Risk	• Client innovation • BIM • Behaviour change • Software and technology

Table 4.4 displays the connections found between the core themes. An example of these links can be found between '*client power'* and '*client innovation*.' The client holds the balance of power in construction projects and so therefore by default is the key innovator (Ahmed and Kangari, 1995; Ryd, 2014; Kamara et al., 2002). If the client demands the implementation of an innovative process, whether that is technology based or strategy based, any innovation will ultimately be down to the client. In view of this, client innovation was not only linked to client power but also behavioural change and risk. The implementation of any behavioural change would need the motivation of the client to provide the impetus; the client has the power to take risks. In addition to this, he or she may indirectly influence educational training programmes, particularly if a specific request for a new strategy or software was implemented.

4.4 <u>Phase two – expert interviews</u>

The analysis of the interviews took a slightly different format to the focus group, which was primarily aimed at testing the relevance of themes identified in the literature. The interview data analysis was carried out in three stages, firstly a content analysis was carried out, followed by an assessment of the core institutional pressures encountered which underpin the themes. These were marked in the coding matrices using 'mimetic' 'normative' or 'coercive' pressure (M, N or C). The objective of this method was to understand whether the changes which had been made or could be made were due to external pressures, social and institutional norms or by companies seeking legitimacy through mimicry. Finally, the findings were assessed through the lens of diffusion theory. Any new work strategy or technology would be required to diffuse throughout the construction industry in order for

overall emissions to be lowered. In addition, communicative networks and influential pathways (essential concepts of diffusion) were assessed throughout the supply chain to understand how barriers to the implementation to low carbon innovation could be overcome using diffusion techniques.

4.5 Content analysis of interview data

Themes for the expert interviews were initially generated by the literature review as shown in Figure 4.2. The selected themes were formulated into questions that were tested in the focus group for their suitability. The themes from the focus group findings were then used as indicators for thematic analysis of the interview data, as the transcripts were assessed for evidence of selected themes. Some themes were adapted and some were removed due to low frequency, however, the literature review and focus group findings developed the themes for analysis of the interview data.

The content analysis of the interviews was supportive of the focus group findings to some degree as the initial results presented a movement towards the implication of human behaviour in CO_2 emissions analysis. The content analysis was also in line with the behavioural deficiencies found in the existing literature in CO_2 LCA. The thematic content from the interviews was focussed predominantly on human behavioural and managerial concepts such as supply chain integration, collaboration and client power. BIM was also a key feature of the data, indicating the continued weight placed on software and technology; suggesting a need for technology which cannot be ignored. Interestingly however, the importance of technology was not as prevalent in the interviews as principally suggested in the focus group findings. The key themes found in the interview data are shown in Figure 4.3.

The themes from the content analysis of the interview phase of data collection showed similarities with the literature and focus group, demonstrating the importance of human behaviour. The interview data differed from the focus group findings in terms of the lack of emphasis on software and technology. Software and technology were generally not discussed in great detail, although BIM was at the forefront of technological developments. In addition to this, the theme ‘client innovation’ was re-evaluated and adapted to ‘client influence.’ The pressure with which a client can be influenced was found to be the cornerstone of the innovative process. The frequency of the key themes were found by highlighting frequencies of certain words to assess the number of times each theme was referred to in the text.

Interestingly, in the interview findings, BIM was not as significant as the focus group suggested as other human based concepts gained greater momentum. The frequency of these themes is presented in figure 4.4.

Figure 4.3 Content analysis: Interview data

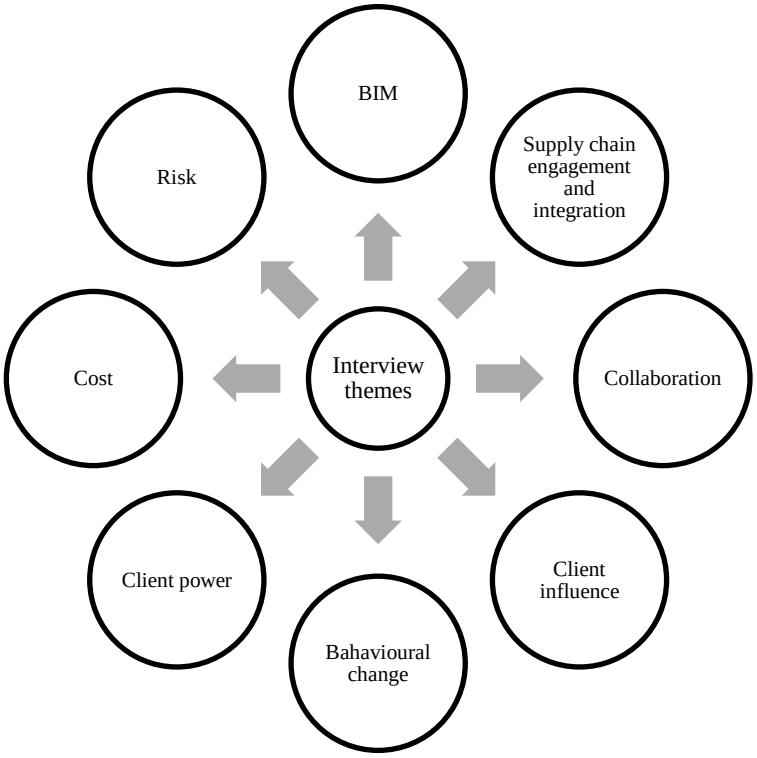


Figure 4.4 Interview data: Theme frequency

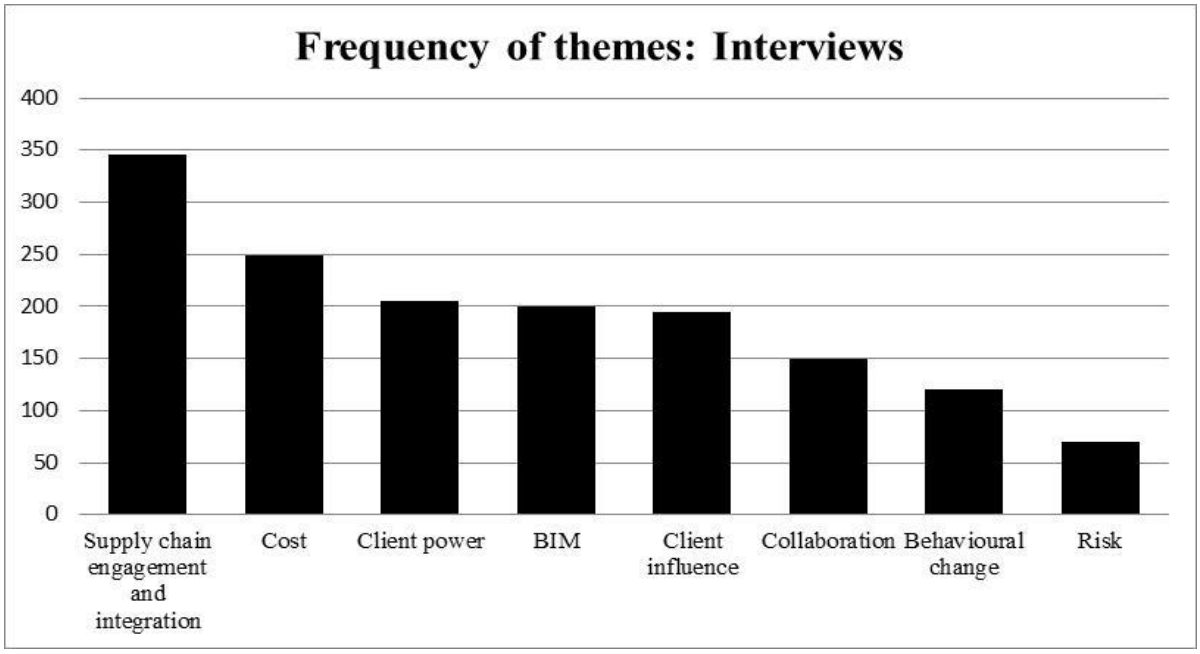


Figure 4.4 displays the emphasis placed on behavioural concepts of CO_2 LCA in the data. The interviews revealed a deeper acceptance of supply chain integration, which was most frequently alluded. Acknowledgement of the supply chain was particularly relevant to the study as the application of supply chain integration in emissions analysis was considered as the most prominent gap in the literature. Supply chain integration was closely followed in importance by cost, client power, BIM and client influence. Other important themes discussed included collaboration, behavioural change, training and education and risk. Despite the clear movement towards behavioural concepts of emissions analysis, technology was still considered to be a vital part of sustainability in addition to greater human emphasis, advocating a more holistic approach to CO_2 analysis.

4.6 Thematic analysis

4.6.1 Supply chain integration

The findings from the interviews suggested supply chain integration was vital in the industry for emissions analysis. The high prominence placed on supply chain cohesion was evident in the data with the following quotations from the design team (supply chain position 3). The quotations were taken from architects and mechanical and electrical contractors who are present for the majority of any new build:

> *'Separation of duties actually can make it harder to design an environmental building.' (Architect)*

> *'I think it was 2013 it came in, Environmental Product Declaration, so as part of that, every manufacturer of a product that's used in the construction industry must declare their supply chain impacts for that product.' (Mechanical and electrical engineer)*

> *'I think supply chains are a very big … in what I've just said there, supply chain agenda is huge, on so many different aspects because you're upstream impact could be so much more significant than the focus that we've had in recent years.'(Mechanical and electrical engineer)*

> *'So collaboration within the supply chain, within our industry, I think is every bit as important.' (Mechanical and electrical contractor)*

> *'We need to buy from our supply chain and so we need that information and maybe it's our lack of understanding of how to go about asking that from them that's the problem.' (Architect)*

The understanding regarding the separation of duties and fragmentation throughout the supply chain has suggested that the format of the chain is inhibiting data flow, making the low carbon decision making processes more difficult. The data supporting the need for greater supply chain engagement can be found in Table 4.3. In addition to this the institutional pressures (coercive, normative and mimetic) and supply chain position (SCP) have been labelled and explored for each quotation where appropriate. An example of this can be found in the following quotation:

> *'I think there's a lot of good work going on. A lot of people are pushing forward with it and there's a lot of unity between different sectors in trying to get agreement on that work.' (SCP3, N,M)*

The above quotation was taken from a participant at SPC3 as per Figure 3.4. It was considered to represent both a normative and mimetic pressure as firstly, social norms involving collaboration will encourage others to seek the same. Collaboration encourages companies to mimic each other to seek legitimacy i.e. unity between sectors in the supply chain. The data supporting supply chain integration indicated all three types of isomorphic pressure - mimetic, coercive and normative (M,C,N) as shown in Table 4.5. Participants have been labelled by supply chain position (SCP) as per Figure 3.5.

Table 4.5 Supply chain Integration

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Supply chain Integration	'I think there's a lot of good work going on. A lot of people are pushing forward with it and there's a lot of unity between different sectors in trying to get agreement on that work.' (SCP 3)	M, N
	'At an early stage you don't know the full make-up of the building, and so therefore you don't do the analysis and you wait until the end of the building, when it's completed, then you go, there's my analysis, at which point it's too late to actually change anything, and so I think there needs to be shift in to a design stage tool.' (SCP 3)	N
	'Separation of duties actually can make it harder to design an environmental building because you've got to get more people on board to agree with that policy. If there's fewer people and they all agree it'll go ahead. If there's a larger group and most agree but one disagrees, you still might not go forward with the solution to get a much more environmental building at the cost of, say, 1% extra of the building, because their remit is to make sure that the cost doesn't overrun, which isn't actually what should be looked at, because they're not looking at the whole lifecycle, they're looking at an immediate.' (SCP 3)	N
	'During construction I honestly don't think we do [calculate carbon]. After construction we calculate it afterwards.' (SCP 6)	N

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
	'I think the problem is the construction project is made up of loads of part…there's too many bits I suspect. If I'm selling plasterboard that's all I'm really interested in. Do I care which wire you put to it no…There's too many vested interests…I think clients can sometimes pull it all … but individually there's too many components.' (SCP 6)	N, C
	'Umm … it is getting easier. I think … because we're a small part of [Insert company], can we influence their thinking in terms of you know what we're doing, so for example, we put solar panels in and some solar energy, would that influence that's going on in other parts of [insert company] across the world.' (SCP 6)	C
	'There's a … umm … I can't remember if it's a Guidance Note or a Policy, but there's something called … I think we've mentioned it in the past, the Environmental Performance Directive I think it's called, EPD, yes, so every product needs to declare … I think it was 2013 it came in, Environmental Product Declaration, so as part of that, every manufacturer of a product that's used in the construction industry must declare their supply chain impacts for that product, so if it was a concrete beam, the company would have to give an EPD on that beam.' (SCP 3)	C
	'We need to buy from our supply chain and so we need that information and maybe it's our lack of understanding of how to go about asking that from them that's the problem, and equally it could be that there's an operational procedure that we're forcing them in to making packaging or deliveries that are less than desirable in terms of frequency or quantity of packaging, that we're actually the cause of, and if we start to collaborate and deal with them in a less transactional way, then we'll begin to move towards a more collaborative partnership with them.' (SCP 3)	C, N
	'Then we'll be able to have these discussions which means we can come up with the answers that benefit our customers and I think that's kind of the stage that we're at, we're really beginning to have those conversations and I think that's true of across the industry. We're having some conversations with some suppliers but there's an awful lot of sort of transactional beat you down, can you get me this price down, because that's the nature of our industry, which prevents that collaboration happening.' (SCP 3)	C,N
	'We don't start on the projects earlier, so by the time we get to a tender, which is normally our first involvement on a project, umm, the façade's already been designed so the type of services that are going in it, so we can't really necessarily influence that, other than we'll check it to see if it meets whatever.' (SCP 3)	C,N
	'That's what we're thinking of having … it is helping with the collaboration between all parties. The problem at the moment is it's still quite in its infancy really, it's BIM, so not every company is on the same learning curve as what others are, not at the same point in the learning curve, so we're finding there's some steelwork companies that we work for currently don't have the BIM capabilities that what maybe ourselves and an architect might do, so there's parts of the collaboration which is falling down.' (SCP3)	N, C, M
	'Supply chain in terms of suppliers we have some group deals with some pretty big players who are totally on board with it. I think manufacturers are far in a way better at sustainability than anyone else in any other industry from what we see, so we work with like [company] and [company], all them sort of companies, who own like [company] and everything else. They are fully up to speed. Internally we've got our own client stakeholder panel on sustainability and most of them attend don't they.'(SCP3)	C, N

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
	'I think it's about 80% of projects in the UK are done on a design and build so, design and build, the consultant will write a set of performance criteria. It will then go to five/six tendering main contractors, who will then go to their supply chain, and they will have a specific detail that I've given them, or the consultant has given them, and I'll tender it to five or six who will then go to their supply chain.'(SCP3)	C, N

4.6.2 Cost

The second most frequent theme deriving from the data was 'cost.' There was a perception that sustainable buildings cost more and that new technologies in particular are deemed as an additional cost to the build and not a requirement. The importance of cost could provide a reason why the data suggests an increased interested in holistic and human based approaches to CO_2 LCA in the construction industry. The notion is that by reducing business risk with high monetary expenditure on technology which may fail, a human based system could provide a low cost solution. The supporting data for cost are explored in Table 4.6. The perceived institutional pressures which were predominantly coercive and normative are also displayed. As the key decision maker in the supply chain, the client is also in control of project funds, indicating the complex and interconnected nature of sustainability issues.

Table 4.6 Cost

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Cost	'In that our perspective is very much the contractor at a certain point, and they really just go about cost and trying to get the thing built and completed so that's … umm … when they're trying to get hold of something it's always to do with how much it costs.' (SCP 3)	N
	'Yes. Because, like I said, that's what is … there's not really a driver for anyone to take it up because you might like to think that people do it because they think it's for the benefit of the environment, but it's the cost of such a driver that umm.' (SCP 3)	N
	'The perception is that certainly to capital cost that anything environmental costs more, umm, and as a lifecycle cost is generally about reducing long-term often maintenance costs and cost environment that way, energy efficiency, it tends to add to the capital cost and reduce the total costs, environmental and monetary, so it's not to the advantage of the person building it, it is to the advantage of the people that are going to run and maintain the building, but I don't know, maybe just not informed enough.' (SCP 3)	N
	'Cost. That's it. Cost and probably how well informed people are and what assessment tools there are around umm … but cost is really the main driver I think. If it was shown to be more cost-efficient then … in whatever way.' (SCP 3)	N, C
	'I can see why you're arguing for that, it's really nice that you care, but it costs too much, usually, is the end result, it's too difficult, costs too much, takes too long, too complicated.' (SCP 3)	N

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
	'Yes, I think, because it's so money driven, I think focusing on the consumer and I do think that, yes, developers do see that as valuable, so if the consumer can be encouraged to demand more sustainable buildings, then they will make them.' (SCP3)	N,C
	'I know it sounds a bit ruthless but we obviously work to a price really and we'll do as much as we can. We'll do whatever we can to meet that specification. We'd love to spend time looking at the carbon analysis of buildings probably a bit more, but because it's a competitive industry, we've got to keep our design costs down to a minimum as well, so we'll design the building, so it meets the regulations, meets all the carbon requirements, in the specification, and then unfortunately it's time to stop.' (SCP3)	C
	'One of the things I think you said was because it's quite innovative, some of this, it can be quite expensive and I think that's a clear barrier isn't it really. It's a commercial world. We're here to make money. If it's commercially viable we will start using it. If it's above and beyond what you'd normally pay to build a property, for instance, you're not going to choose that, so it needs to be competitive.' (SCP 4 & 2)	C
	'In 2007 the demand and the interest in sustainable construction was, I think, at a high, but it was very very high on people's agendas. Then 2008 came, credit crunch, construction industry basically demand for new buildings, in particular, types of buildings that we're involved in, industrial, logistics buildings, that type of thing, it fell off a cliff. ' (SCP 5)	C

4.6.3 Client power

Client power was also a prevailing theme found in the interview data, confirming the preliminary findings in the literature review and focus group. The theme of client power was found throughout the entire interview data collection process as the supply chain was ultimately directly responsible for the client's needs. In addition to this, client power was also supported by other important themes such as cost and client influence. The core supporting data for this theme is explored in Table 4.7.

4.7 Client power

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Client Power	'No one talks about lifecycle costing or … much, mostly because I think we do … the vast proportion of our schemes are design and build contracts which means that the … your client, during those stages, is the contractor, who doesn't care about anything but the capital costs of the building.' (SCP3)	C
	'Unless it's something they have to do, because it's written in to the contract, it's not going to be a concern of theirs really. It tends to be a tick box exercise.' (SCP3)	C
	'It's whether or not there's a client or someone who is willing to pay for it or wants to tag that on as something in their building, so you know, in that respect.' (SCP3)	C

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
	'They choose not to because they don't have to, and therefore it's a cost saving, and it would … and, at some point, it's all driven by that. The … if it was built in to various employers requirements that they had to use it, then they would, but that would bump prices up, and it's … unless people have to use something they are not going to choose to, uhh, at the more contractor end of the scale. So it's really down to the clients deciding it's important enough to build in to the requirements.' (SCP3)	C
	'Yes, whoever's paying for it, is the person that needs to say that that's important, yes.' (SCP3)	C
	'So it's really down to the clients deciding it's important enough to build in to the requirements.' (SCP3)	C
	'The contractors and the clients don't necessarily want it. From our point of view it's either been legislation driven or PR driven from within the company.' (SCP3)	C
	'But others can be quite pro-active and say, okay, how can we make this more sustainable because they've got a vested interest in sort of the longevity of the building, so it really depends on the client and what they want to do with it after.' (SCP3)	C
	'On the lower end of the spectrum clients are normally just driven by money rather than sustainability, unless there is a reason for it to be sustainable, and that's where I go back to the sort of the PR side of things.' (SCP3)	C
	'Certainly clients are becoming more involved as more pressure is put on them. There's still a bit more legislation to go I think before it will become mainstream.' (SCP3)	C
	'It's the clients who are pushing the agenda and leading professionals who have those same attitude.' (SCP3)	C,N,M
	'Well I think … I don't want us to do things from a sustainability point of view or energy savings point of view, just for the sake of doing it, so for example, we looked at wind, could we do something with wind, but I mean, the investment which is a barrier, it's the amount of investment and the pay back, you look at putting wind turbine on, it was something like 12 years pay back, so we ruled that out' (SCP 6)	C
	'So yes, clients I think are absolutely pivotal to this and that doesn't have to be a retail … a physical retailer with physical customers, I think in some of our bigger engineering construction contracts, industrial and infrastructure, clients have very strict requirements too, and things like the Social Value Act, if you're working on a public sector operation, public sector contract, should also change the way, even if they don't quite necessarily understand what they're necessarily asking for, should also influence things too, so yes, a very big part of it.' (SCP 3)	C
	'Hmm … that's a difficult one that is. I think … well, the client's got to ultimately lead it, and has got to want it, and I think if they lead it and want it, it'll get in to everybody's head that it's going to happen. Whether it's the architects that sort of … takes the lead or the services consultant, I'm not sure.' (SCP 3)	C,M,N
	'Yes, it's probably … it's not really asked for. As soon as that becomes integrated in to specifications then that's the kind of thing that we'll obviously have to target. At the minute it's not specified, therefore, being the contractor, we're the guys who install and it's driven by price and the performance	C

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
	specification, so it's being specified, we've got to meet that at its lowest price, so therefore it's not there, it's very easy just to say, we don't care.' (SCP 3)	
	'I do agree with that and there's many clients like that, but you also do get the clients that don't agree with that, and just want the cheapest building possible, to be up as fast as possible.' (SCP 5)	C
	'We are driven by clients, if we're honest. We try and impart our requirements in to their … requirements, what the clients give to us… Obviously driven by the HCA's and the Governments and all the other relevant bodies, but they tend to go the bare minimum because of cost … we're largely driven by clients and we try to impart ourselves on them but, if they don't want it, they don't want it.' (SCP 5)	C
	'Modern methods of construction is … it's client-driven perhaps more legislation but within that you then get building regulations change to suit and you can't built it until you get building regs approval so, yes, it pretty much is, it's a compliance issue.' (SCP 5)	C
	'Client design is the driver still rather than it be, okay, this is the industry preferred solution, or preferred options' (SCP5)	C
	'We Actually worked on a scheme at HMP **…**that's some time ago now, 2007/2008, where the BREEAM ratings for each of the buildings was very important. The design drive of ventilation, natural ventilation, and natural light, was a major contributor towards the design, so I would say the Ministry of Justice at that time were quite … what's the word … innovative. Latterly, I would go back and reiterate, a lot of the Authorities, Local Authorities, are very much driven by consultancy and so the consultancies remit is often pick the best company who will deliver on time, at the best price, so …' (SCP 5)	C
	'It can't really have an effect because people aren't engaged early enough and is there an appetite for it. Well, again, I see it, from experience, and this is just my working experiences, there is no appetite to measure the building energy through its whole lifecycle unless it's prompted.' (SCP 5)	C,N
	'It could be influenced by consultants, engineers, it could be influenced by architects and the professionals and academia, but the ultimate is well I'm paying a bill, do I really want that, I say, do you know what, I see the value in it, because I'm running the darn thing for the next 25 years, so I would say they are the most influential people, is the end user of the building.' (SCP 5)	C
	'I mean I've been in plenty of meetings where the client has had a wish to have renewables on his building, but then when it comes to the crunch, does he want to pay the extra money for it, and quite often the answer's no. I'd love to have that but the pay back's not quite good enough for me. ' (SCP 4)	C

4.6.4 Building Information Modelling (BIM)

The continued significance of BIM was still considered to be an important element of future emissions analysis. The implementation of BIM could be acknowledged as a coercive pressure. The UK government have put forward recommendations that all new buildings must be built using BIM where appropriate by 2016; therefore the industry may be forced into using it. Despite governmental coercion, all three types of institutional pressure were

found to underpin the use of BIM in the data. With a significant government backing, this type of implementation may be advantageous to the development of future emissions analysis. BIM continued to be the predominant technology discussed in the entire data collection process. The implementation of BIM is explored in Table 4.8.

Table 4.8 Building Information Modelling (BIM)

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Building Information Modelling (BIM)	'Enormously important. Yes. Umm … in theory. It's … we're some years off the practice catching up with theory but, yes, it should be, because the idea is that with all the data that will be attached to the 3D models, and particularly with the way that umm … the process of design and procurement means that you have to bring forward much earlier in to the process a lot of the nailing down what something is, or more likely.' (SCP 3)	C
	'Yes. No. We have all the software to do it, we have BIM, we are currently going through the training process, yes, we're getting … we've got a new architectural technologist to come in, especially to help us with our BIM strategy, and BIM software, and we've all got it, we've paid a lot of money for it, and nobody's using it in the office yet, so …' (SCP 3)	C,N,M
	'Well, if we look at BIM now, and what it's used for, it's required for every Government project, it's not yet required for every construction project.' (SCP 3)	C
	'It's not a joined up process at the moment. It's … we get a BIM model and we work with it to co-ordinate and that's as sort of as far as it goes. I think it's a very powerful tool and the … it does seem like a logical way to go because if you could take a piece of information, if the embodied carbon was in there, and there was some way of putting where its come from and things like that, I think the … sort of the way to go.' (SCP 3)	M
	'Because we're at design we're almost expected to have an understanding of BIM where, in reality, it's everybody, it's the estimating team, it's our procurement team, everyone's got to be able to buy in to it and understand that it's a process, it's not … we kind of … we frown when people suggest it's just a model, it's obviously not that, it's much bigger.'(SCP 3)	N,M,C

4.6.5 Client influence

Adapted from the focus group client influence was found to be an imperative theme in understanding emissions analysis. Linked to the power of the client and supply chain integration, the client as the key decision maker holds the power to make the final decisions on sustainability. The acknowledgement of client power in the data collection process in some instances led others, specifically the design team to question whether greater influence should be exerted over the client to encourage greater sustainability outputs. The relationships between the client and the supply chain and their potential influences on each other are supported by the data displayed in Table 4.9.

Table 4.9 Client influence

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Client Influence	'Unless in a way, as part of an architect's obligations, once you're' in a relationship with a client, you do have an obligation to inform them of a lot of things, whereas I don't think you have to do anything to do inform them about how environmental they would have to be, you know, because you do have to be safe, you do have to be … there's other factors that are included.' (SCP 3)	N, C
	'But in answer to your question I don't think the client is probably very well informed because, yes, who would be the person to inform them really. Would it be architects once they've … once you're at RIBA work stage 1 kind of thing.' (SCP3)	C
	'You know develop a relationship with the client, so that they continue to make sure that the building functions as it should do, I think that can certainly help sustainability, and I think that's what a lot of good practices do who are committed. They develop bonds and relationships with the client and manage multiple buildings and, in that way, they continue to come back and check and refine and resolve issues, you know, every building is a new thing and there are always going to be minor little things that go wrong, sometimes they're major, umm, because you're testing something in an unknown environment.' (SCP3)	N,C,M
	'Those decisions are made predominantly by us as the … well, my boss, myself, umm, and we have some directors within [company] that support us, so they're the key people that would make the decisions on what we're doing. Key partners for us are people like [company] who deal with all our M&E, so they can influence what we're looking at because a lot of the product that we've got has got a shelf life and we challenge them, you know, something like, for example, the energy that's coming out of ambient loop, we're challenging them to find a way of turning that to energy, that heat to energy, so I think they've got a key part to play in our decision making about the products that we have and we install as we go forward, umm, but other than that, there's not a lot, from a building fabric point of view, we have what we have, so our building fabric manager might have some input in to it, but it's more around I think … for the smaller bits that we do it's more around umm … those investments in terms of M&E etc.' (SCP 6)	N,C,M
	'It's because they were poorly sited and there was problems with where they were located and the client could have been better informed as to where they wanted it, etc. etc. and also it was an early deployment of the technology that they thought would work and wouldn't work, but the fact was, it got the perception out there that this green stuff doesn't work, umm, and I think that's probably true. I think with lifecycle analysis generally, and I don't know how it would apply directly to lifecycle analysis software, but I think generally with lifecycle analysis there's a certain degree of, like I said, cynicism.' (SCP 3)	N, C

4.6.6 Collaboration

Although not as prominent as suggested in the focus group findings, collaboration was a central theme found in the interview data. Collaboration was a core factor in all of the human behavioural concepts of CO_2 emissions analysis via the supply chain. Table 4.10 highlights the supporting data conveying the potential importance of increased collaboration and the

institutional pressures faced by collaborative processes around low carbon decision making in construction.

Table 4.10.Collaboration

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Collaboration	'People do collaborate all the time actually. People who say we don't collaborate, it's not true, we just don't collaborate very well I think because you have to … it's all part of various teams or supply chains. You have to work with each other otherwise the whole thing's impossible. But there's a lot of entrenchment of positions and a lot of obscurity of information because people think that they'll be at a financial disadvantage say if everyone knew how long it was actually taking them and how it was actually costing them.' (SCP 3)	N
	'I don't know, it's more the suppliers in the supply chains, because there's some very hard-nosed bargaining goes on…the more collaboration within design team levels…in theory [Collaboration will improve]… all the way down the structure.' (SCP 3)	N, M
	'But perhaps if we did know more about the concerns of the other disciplines, and everyone did, which I guess will, by enforced collaboration, because of BIM being brought in, would be nice to think that would help that happen and one of the reasons they talked about wanting to bring BIM in, rapidly, is that the more conceptual architectural stuff, at the beginning, will be assessed much more transparently in terms of the how the build-ability of it, and umm … cost and supply chain and so on, and the other way around, we'll get to understand more of those concerns I think from an architect's point of view, but it would be the same throughout the disciplines.' (SCP 3)	N, M
	[via BIM] 'Yes, yes, certainly, I mean, having multiple organisations working on the same model, adding in the M&E, adding in the services, has been very useful to check drawings that everything's there and you are building it in 3D so everything is … is there that should be there, you're not missing things. I mean the Government wants it to be I think going to a unified model run off of servers where everybody can access this at one time. I think that's a bit of a long way off. I think segregated models where each one shares and then it comes together in a central model every so often is more realistic given limitations on internet speed and other things, even us in Central London we can't get fibre optic, we've been trying for a year now, it's hopefully coming soon, but … you just don't have the speed to do that, if you haven't got that sort of fibre optic cable network.' (SCP 3)	N, M, C
	'The best projects are built from that relationship and you'll say, oh, well we'll try this and we'll refine this and we'll develop this further and further over more than just one project so I think that level of enhanced collaboration does work well.' (SCP 3)	N, M
	'Yes, well, again, you know, I mean, I do like the collaboration kind of world because you do build partnerships up, you do see … other people's ideas come forward umm and you can develop those, so from a project starting, if you've got that collaboration … that true collaboration in there and you're listening to people's ideas, you're listening to people that view things slightly differently, then you can get to a good solution.' (SCP 6)	N, M
	'No, it doesn't happen enough. There are … it's being encouraged but, again, it's … I think it's just such a lumbering beast that's been going on … that's been doing things the way its been doing them for so long, it's very hard. Recent government schemes that have tried to encourage collaboration have all been focused on the economy really and that's encouraging small businesses to form partnerships and work together to win big projects and that has not worked at all, it's nonsense, and	N,M,C

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
	I think that it's the same for a lot of schemes or just desires to work collaboratively. ' (SCP 3)	
	'Yes, I mean, it's a fantastic idea, yes, and it's the … yes, it's a great idea. On paper it works. It ticks all the right boxes. But I think it's … its problem is that greed is so embedded in the industry that it's hard to get people … you need trust for people to work like that. I've noticed it a lot, from coming a bit from academia, where it's all about … or supposed to be about sharing knowledge, in fact, what has happened, interestingly, in academia, the greed and lack of collaboration has crept in from industry and business, whereas before it was a lot more open, so its kind of worked the other way, where you should be trying to take the lessons from academia of old and embedding them in business and construction and development but, instead, its gone the other way.' (SCP 3)	N, M, C
	'Yes. If it's used in the right way and as part of that collaboration platform, yes, that's exactly right, if BIM is used on every project, and there's this thing, called the ICIM, so the Inter Operable Carbon Information Model, I'm glad I remembered that, so that fits in to BIM, so there's already tools out that there can do it, it's just you've got to you know the Government have got to say well this is the way it is, we have to do it.' (SCP 3)	N, M, C
	'So I think in terms of the collaboration that work is beginning to really take hold and it's recognised now that this is something we have to do, we have to start getting a handle on, and that our clients will expect it of us in the future as a number of market leading clients would have incorporated this in to their requirements for certain contracts and bids and tenders.' (SCP 3)	C
	'If you're collaborating you can improve the design a lot more. It's meant to be holistic design isn't it, a building, so if you are collaborating between … if you can say to an architect we could do with the glass improving in this area, we could do the glass modified and changed and reducing its size, I think that's the way that we should go and I think all … it's better if all projects … all parties in the project are involved at an early stage so they can have that input and collaborate between each other.' (SCP 3)	M
	'Collaboration works, but ultimately it's not as easy as just kind of saying that, it's building the relationships, knowing your history, bringing … and then obviously having that competitive edge. Over time, when people have built up relationships with people, they often don't want to let them go and then they'll put the prices up and forced to look at somewhere else.' (SCP 3)	N, C

4.6.7 Behavioural change and risk

The final two most highly occurring themes found in the data were behavioural change and risk. Supporting quotations alongside their corresponding isomorphic categories can be found in Tables 4.11. - 4.12.

Table 4.11 Behavioural change

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5.	Isomorphic category
Behavioural change	'I don't pay the bills, I'll leave the lights on, leave the water on, leave the air conditioning on, so we have got to get a massive change in peoples mind-sets so they take responsibility for the energy they use. If we lose that battle, you know, machines can't do everything, but if you can't simply switch a light off, we're in … we are going to struggle. Not all buildings have been refurbed, so most of the new buildings will have PIR's in the rooms, if you go, they'll switch off. A lot of the estate is 200 years old, old lights, if you don't switch them off, they're going to stay on. If you don't switch the air conditioning off, they're going to stay on, so peoples responsibilities I don't think we've won their hearts and minds yet. That'll be the next challenge for carbon footprint and everything but …' (SCP 6)	N
	'I think … I don't know if using a lifecycle assessment tool to give you an answer necessarily means that you're going to get the real objective of producing more sustainable buildings, so I think if you can … look at other drives, that are just simple behaviour change things, then that might actually be more effective. It gets the same outcome or hopefully a similar outcome but you're not … I guess it's more an under-the-radar of people thinking they're being forced to do something they don't want to do maybe.' (SCP 3)	C
	'I think human beings inherently will always try and get round the problem or solve a problem to their best advantage, so there is a behavioural thing there and, you know, if everyone wanted to save the environment, I think we'd be in a totally different position.' (SCP 4)	N
	'I mean you can modify your behaviour, the recycling thing is a case in point isn't it, you know, if you modify rather than just chuck it in the bin, sort it out, I suppose that's effective, I don't know. Umm … technology, I think you need both don't you really. I think, you know, because … the thing is, for management, you have to put the system in place to allow people to do what you want them to do, so there's no point in … like on a building site, there's no point in saying, right, recycle everything, and not put any bins out. If you put five bins out with five different classifications then tell them to recycle at least they can start to do it, so you've got the behavioural aspect and also you've got this technology or whatever. You're giving them the means to do it.' (SCP 4)	M

Table 4.12 Risk

Theme	Participant supporting quotation & supply chain position (SCP) as per Figure 3.5	Isomorphic category
Risk	'Yes. But even so we had the legal implications of BIM meeting recently when I was … recently when we were talking about that and one of the key things was insurance in that the sort of PI … sort of indemnity insurance you have, if you … they're trying to work out a way of getting to work that promotes collaboration in that you … it's kind of a shared risk, umm, and if you get … because, otherwise, the fear is that if you collaborate too much, you're exposing yourself to be sued if you do something wrong because who knows whose fault it is, if you're … uhh … and so it's often that kind of taking away that fear of being sued for something or getting something wrong and there being mass penalties will help with collaboration I guess. How that feeds in to sustainable lifecycle I'm not sure, but I guess anything that makes a building process more efficient helps.' (SCP 3)	M
	'I guess that's part of the … any level, it's a way of assessing carbon footprint of the design or something. If it's easy to use and readily available then people are more likely to have a go. If it's unfamiliar and you're not sure it's going to work, then I guess … people will be hesitant.' (SCP 3)	N,M
	'There's so many aspects to something. It often is down to personal relationships as well, there's an existing personal relationship and so we'll stick with these people, or it's they've heard that this company is difficult, or this bit of technology doesn't work and they don't want to risk' (SCP 4)	M,N
	'No, no, there are umm … people are keen to try new stuff, but it's normally related to … something they already know and understand I guess, or it's someone, I'm just thinking in much broader terms of Apps on the I-phone, someone shows you there's a kind of … look at this, this is how you use it, and it's really easy.' (SCP 4)	M
	'Your client, you'd have to persuade them that, you know, well actually no one's used this before, but I think it's great, yes, people hate that. If no one's used it before…' (SCP 3)	N
	'Yes. But uhh the innovation is risky and that's why you wait for someone else to take the risk often, unless you are one of those innovators, and then when it looks like it's okay, then other people take it up, so …' (SCP 3)	M
	'I mean if there's a way of … there is no way of reducing the risk with innovative stuff, other than to do it, and test it and see what happens I guess.' (SCP 4)	M
	'But you need to be of their size and … capability to take those risks because then, when it does go wrong, they're not going to … they won't suffer from it, you know … in the long term, and then everyone benefits from it, that is true, like as much as people say about them, the whole industry benefits, once they've tested it.' (SCP 3)	M, N
	'Ultimately yes. Ultimately people are looking at cost, risk, compliance, profitability, stuff like that. I think, at the moment with carbon, it's just … it's still so low down the pecking order and things are not really considered as much as what it should be, but I think that will change over the next five to 10 years. I think it will have to become more important because of the Climate Change Act.' (SCP 3)	C
	Yes, I don't think anyone wants to put their name and sign up to a technology on a building that's obviously going to cost more money and they've got the feeling, well, is this going to pay back, you know, is this really going to work for my client, if it does, who is going to carry the can for that, yes, risk, yes' (SCP 4 & 2)	C

Tables 4.5 - 4.12 provided evidence of the institutional pressures which impact on the key themes extracted from the data. Each theme delivered evidence of all three institutional pressures - mimetic, coercive and normative, however some pressures were more relevant to certain themes than others. Table 4.13 summarises the pressures which had the most impact on each theme alongside explanatory examples.

Table 4.13 Institutional pressure summary

Theme	Primary Institutional pressure (the pressure with the greatest impact on the theme)	Explanatory example
Supply chain integration	Normative & coercive	Normative pressure may result from social norms i.e. it is socially accepted to work within a linear chain. Coercive pressure might be a consequence of contractual obligation.
Cost	Coercive	Financial restrictions were found to heavily govern the outcome of construction projects. These restraints are coercive as they are enforced on the project.
Client power	Coercive	The client primarily exerts coercive pressure over the supply chain as they must adhere to client demands. Additionally the client is also impacted by coercive pressure from construction contracts and finance.
Building Information Modelling (BIM)	Normative & elements of coercive	It is considered a social norm to provide technological solutions to problems. The coercive element of BIM implementation came from governmental procedures to use BIM on all appropriate new builds by 2016 (HM Government, 2016).
Behavioural change	Normative	Behaviour was found to be driven by social norms and so therefore heavily impacted by normative pressure. Expected behaviour was often continued for fear of losing legitimacy.
Risk	Mimetic	Risk was most highly affected by mimetic pressure. Those working in close proximity were found to be more likely to take risks on low carbon innovation if they could view success from others within their social set who were using the innovation. The perception of risk is reduced as uptake increases and others take on an innovation for fear of losing legitimacy.

4.7 The construction supply chain

The final round of data extracted from the interview process was specific to the construction supply chain. Participants were shown a typical construction supply chain and asked to assess whether they thought the supply chain aided or discouraged low carbon decision making processes. Interestingly none of the participants agreed that the supply chain made the

process of low carbon decision making easy. It was primarily thought that the main reason for this could be the linear format which made collaboration difficult between the two poles of the chain. Participants were shown a typical construction supply chain (see Figure 2.3) and asked to reconfigure it to address how the position of supply chain actors could aid the collaborative decision making processes via influence.

Figures 4.5 – 4.8 highlight the key changes which were suggested by interviewees to the supply chain structure. The new supply chains were created firstly by categorising the reconfigured chains into the following sections; design, management, sub-contractors and clients as these sections were considered to have the most influence over carbon outcomes. Each diagram was then assessed and analysed to compile a single supply chain which incorporated all of the key changes from all of the participants in each supply chain section. The experts which were attributed to each section can be found in Table 4.14.

Table 4.14 Breakdown of experts in supply chain sections

Section	Experts
Client	The construction client requests the building
Management	Project manager, main contractor
Design	Architect, quantity surveyor, structural engineer, mechanical and electrical contractor
Sub-contractor	Any business which will perform part of the build, i.e. ductwork
Manufacturer	The businesses from which all components are sourced
Raw material extraction	Businesses which provide the raw material to make components i.e. aggregate for concrete

Each supply chain section challenged the rules of data flow which currently form a linear arrangement (see Figure 2.4), emphasising the importance of influence pathways throughout the chain. The spectrum of influence and communication is essential; understood in this research through the use of diffusion theory, aiding the explanation of the adoption of innovative processes throughout the chain. Arguably the most relevant finding was that the client's power in the chain could be inhibiting the development of emissions analysis. Overall the client made the least number of changes to the supply chain. As the supply chain actor with the greatest power, the client has the authority to innovate and in its current format, only then can the innovation filter down the linear supply chain. The use of diffusion theory to explain the phenomenon of how innovative work strategies and processes could filter throughout the construction industry will be explored and discussed full in in Chapter 5.0.

Table 4.15 Reconfigured supply chain key

The red arrows within each reconfigured supply chain indicate that a change has occurred from the original supply chain design (Figure 2.3).

Output	Meaning
→	The solid red arrow indicates where the supply chain section promoted a need for greater collaboration or influence.
- - - →	The intermittent red arrow indicates a movement. The movement may be a complete removal from the supply chain or movement to a different section of the supply chain.

Figure 4.5 Design team supply chain reconfiguration

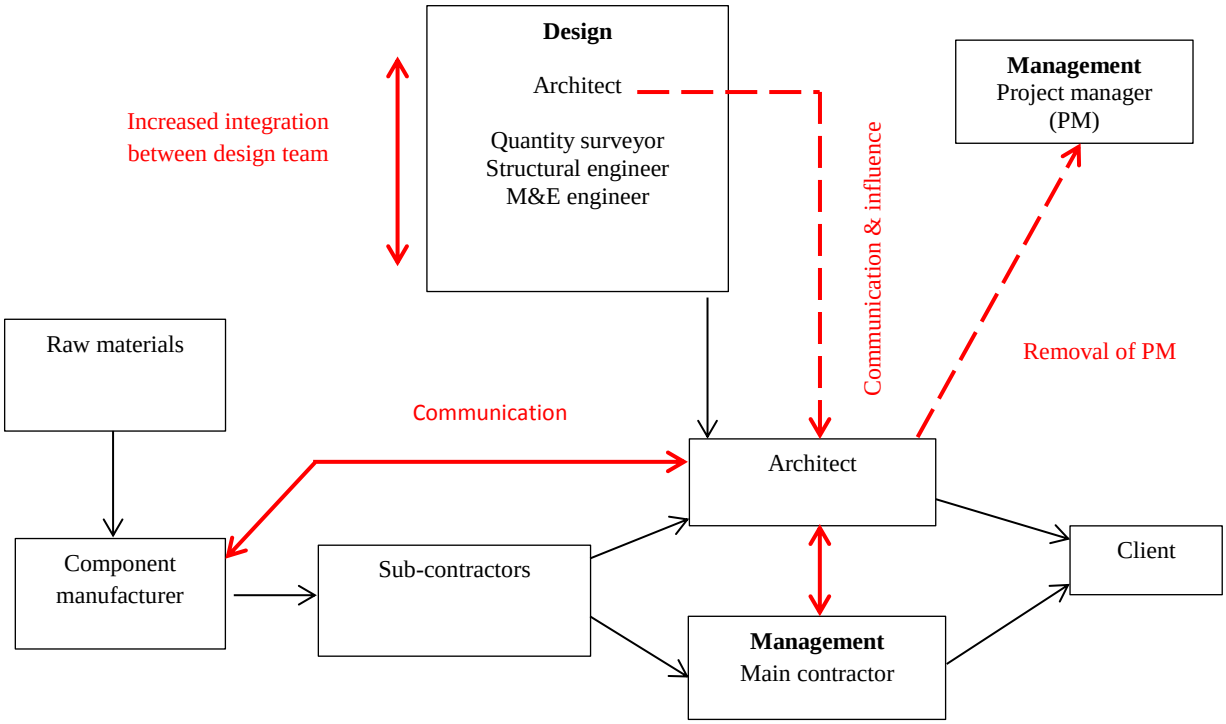


Figure 4.5 demonstrates the reconfigured supply chain created from the design section of the supply chain as per figure 3.5. The design team were heavily focussed on the architect and the importance of increased communication between the design team and the client. They

advocated the removal of the project manager and advised placing the architect in the project manager's position. They indicated that this would reduce information delay and distortion whilst simultaneously easing the flow of communication between the client and the architect. They argued for the need for increased integration of the design team and greater communication between the architect and the management team. Additionally increased collaboration between the manufacturers and the architect was suggested in order to make more informed low carbon decisions.

Figure 4.6 Management team supply chain reconfiguration

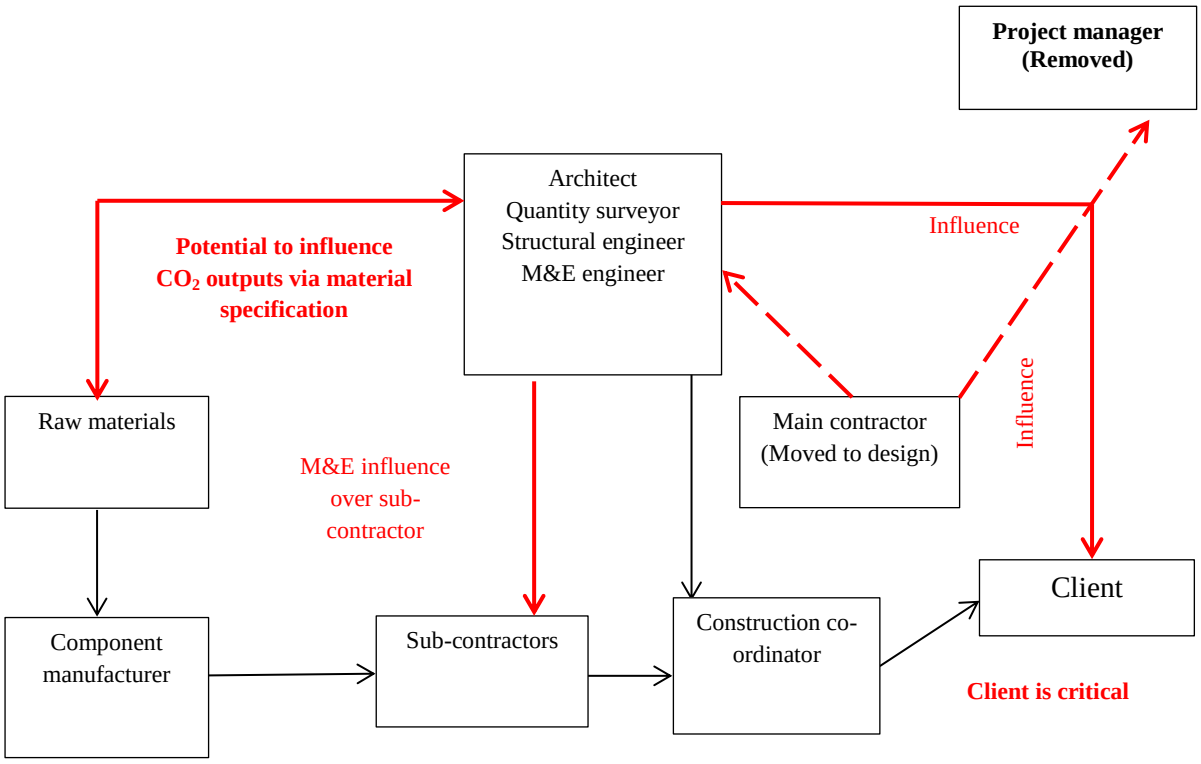


Figure 4.6 was compiled from the management team's responses to reconfiguring the construction supply chain. Similarly to the design team, the management team also argued that the project manager should be removed from the system. In this instance however it was argued that a construction co-ordinator should take the position. It was thought that this would increase collaboration between supply chain actors as information did not need to pass through so many individuals to reach the client. The main contractor could then be moved to the design team, exposing the individual to greater levels of information. The management team advocated increased influence and collaboration throughout the chain, specifically between the design team and the sub-contractors, raw material extractors and the client (in view of the main contractors move to the design section). The client was deemed as a critical component of the supply chain. Greater collaboration and influence between the

client and the rest of the supply chain was thought to be essential for the development of low carbon construction.

Figure 4.7 Sub-contractor supply chain reconfiguration

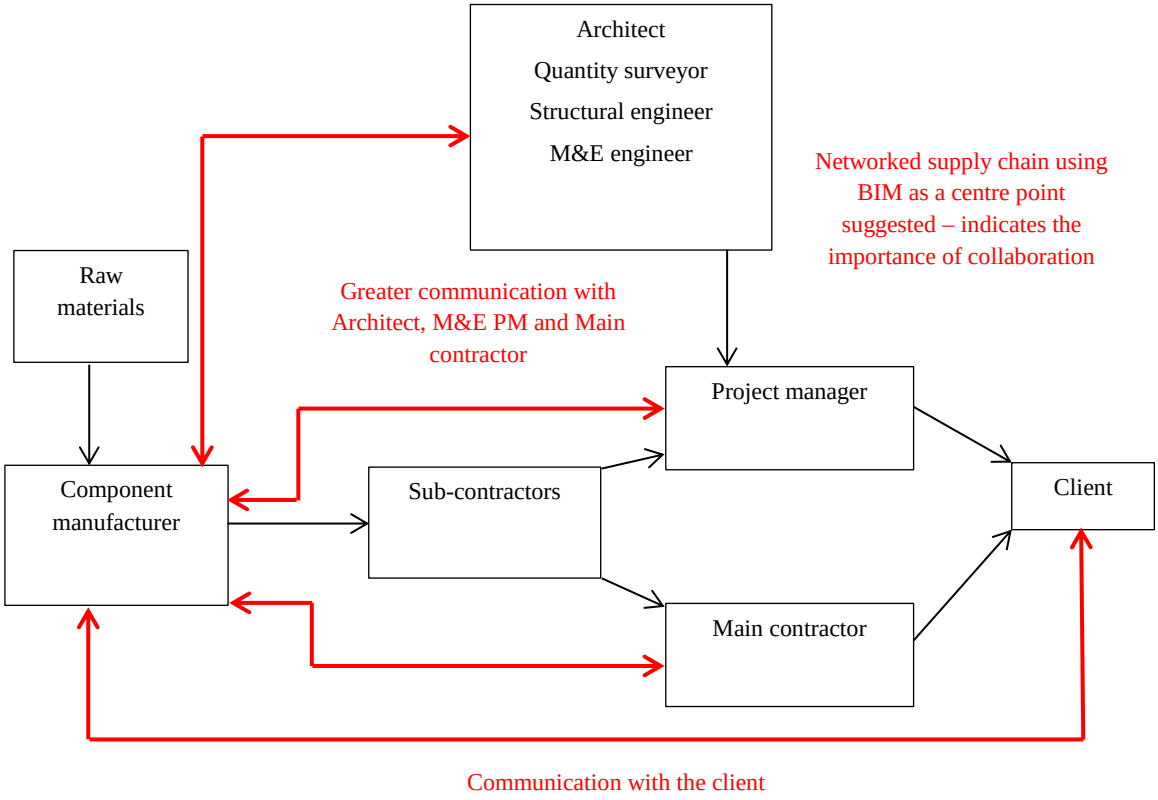
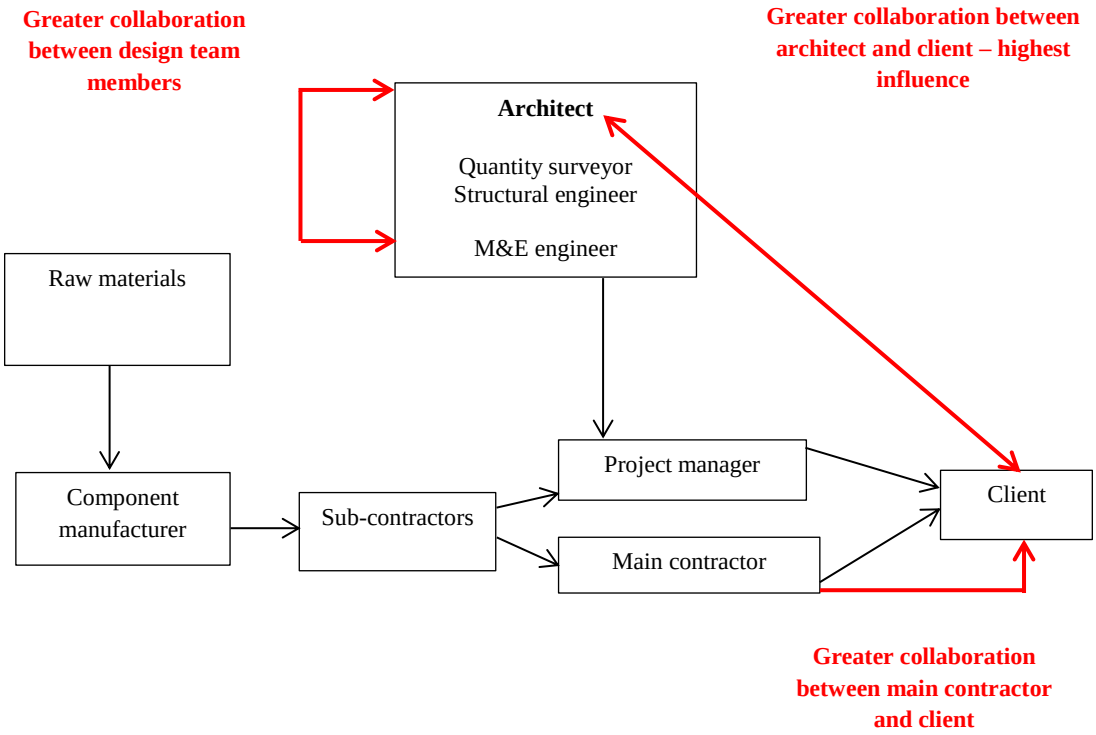


Figure 4.7 displays the output from the reconfiguration of the construction supply chain by the sub-contractor participants. The sub-contractor section was heavily supportive of increased collaboration between all supply chain actors as figure 4.7 indicates. In particular it was suggested that there was a greater need for the poles of the chain to communicate. Additionally it was argued that more collaboration between manufacturers and the project manager needed to occur, in order for the project manager to become more informed about the manufacturing process when sub-contractors were requested for certain activities. For example the project manager may be more informed regarding difficulties in locating low carbon components before requesting them. Furthermore increased communication between the architects, mechanical and electrical engineers, project manager and main contractor was considered to be an important factor for sustainability. Interestingly, in this case the sub-contractors advised that creating a network of collaboration using BIM may be an option for increasing integration, heavily enforcing the importance of the collaborative process.

Figure 4.8 Client supply chain reconfiguration



The final supply chain reconfiguration was carried out by the client section of the supply chain. As the client holds the most favourable position it was not surprising that this section made very limited changes to the original supply chain design. The clients neglected to acknowledge the supply chain beyond the main contractor. The focus for these reconfigurations was primarily on the main contractor and the architect. The importance of the architect was acknowledged and increased communication with this particular supply chain actor was advocated. The influential pathway between these two supply chain actors was heavily alluded to. There was also a suggestion of the need for greater collaboration between design team members and finally, greater communication between the main contractor and client was proposed. Overall however the client did not feel the need to make revolutionary changes to the structure of the supply chain. The lack of change was attributed to their powerful position in the construction hierarchy.

4.8 Chapter summary

Chapter 4.0 has outlined the results of the data collected from the focus group and expert interviews. The content analysis from the focus group was used as an exploratory mechanism to validate further testing. The interviews have been analysed using three methods. Firstly a content analysis was carried out, followed by a thematic analysis of institutional pressures that resonated from each theme. In addition to this an analysis of the supply chain was also carried out to understand how a new low carbon strategy could potentially diffuse throughout the construction industry, aiding CO_2 emissions analysis. The findings provide an indication that a lack of collaboration and supply chain integration could be inhibiting the diffusion of sustainability. In addition, the application of institutional theory has provided grounding for considering how institutional pressures faced by the construction industry affect the diffusion of low carbon practices. A full analysis of the data will be carried out in Chapter 5.0.

Chapter 5.0 - Discussion

5.1 Introduction

The predominant focus on technology in construction LCA literature has meant that very little attention has been directed at the wider picture of supply chain behaviour (Alcorn and Baird, 1996; Sartori and Hestnes, 2007; Abanda et al., 2003; Koh et al., 2013; Jervis et al., 2014a). With software saturation, poor diffusion rates and CO_2 emissions continuing to increase in the industry, questions surrounding whether solutions to the emissions problem are technological or behavioural have emerged. It was the intention of this research to firstly understand why despite the abundance of LCA technology, CO_2 emissions in the construction industry continue to increase. Acknowledgement of technological failure provided the impetus to seek the impact of behaviour on the implementation of low carbon strategies by using a supply chain perspective for emissions analysis. The research endeavoured to understand how collaborative supply chain networks can aid low carbon decision making in construction using institutional theory and diffusion theory. Qualitative research has been used to underpin the task of answering the key research questions focussed on developing a new perspective for addressing carbon calculation.

Chapter 5.0 discusses the key findings from the data collection process. It will address the meaning of the findings in a supply chain management context and present their application to the existing literature. DiMaggio and Powell's (1983) institutional theory was used to provide an understanding of how institutional isomorphic pressures aid or inhibit the development of CO_2 emissions analysis in construction. The data were then considered using diffusion theory (Rogers, 1971) to assess and underpin the potential for a new LCA system or strategy to move through the industry in the wake of isomorphic pressures. Used in conjunction with the supply chain, institutional theory and diffusion theory enabled an assessment of how communication flow and influential relationships aided the uptake of innovation. Supply chain and adopter category correlations were used to explain the origin of innovative processes. The following research questions were considered in this chapter for full appraisal in chapter 6.0, whilst the development of a collaborative framework for low carbon decision-making processes was formed.

RQ1. *How can low carbon decision making strategies diffuse throughout the construction supply chain?*

RQ2. *How can the implementation of low carbon decision making strategies improve a firm's legitimacy in the construction industry?*

RQ3. *What provides the impetus for construction companies to take on low carbon decision making innovations?*

The structure of this chapter firstly addresses the key trends found in the data. Each theme is then assessed to understand the impact of institutional isomorphic pressures on the diffusion of low carbon innovation. The data was divided into six key areas; supply chain structure, collaboration, client power, cost, risk and technology.

5.2 Trends in low carbon construction

The findings of the data collection phase were consistent with the literature and emphasised the human based deficiencies and technology prominence (Adelberth, 1997; Adelberth, 1999; Abanda et al., 2013; Alyami et al., 2013; Baek, et al., 2013). Codes generated from the literature and both phases of data collection consisted primarily of human based concepts; however, interestingly there were clear differences between the focus group and interview findings regarding the importance of technology in low carbon decision making. The differences in empirical findings are indicative of the emerging changes in carbon emissions solutions, indicating a technological – behavioural shift.

The focus group data had a prominent focus on technological solutions and particularly on the implementation of BIM which had a 42% share of the focus group discussions (see Figure 4.3.) Despite this leaning there was an indication of a movement towards a more rounded approach to carbon analysis and low carbon decision making due to the collaborative elements of BIM (Hardin, 2011). Although in the focus group BIM technology still took precedence, there was a greater acceptance of other factors which could provide low carbon outcomes. These features included aspects of behaviour such as collaboration, supply chain integration, behavioural change, training and education and client power. The thematic literature correlations used to develop the coding practices for this research meant that some themes were expected to underpin the literature.

The interview data collection process confirmed the movement away from purely scientific and technological solutions to the emissions problem. As the data collection progressed the most highly occurring themes were somewhat different to the technological emphasis in the focus group findings (Alyami et al., 2013; Baek et al., 2013). In the interview findings supply

chain engagement and integration was the most significant theme, followed by cost, client power and BIM. Interestingly BIM had dropped significantly in importance, as supply chain integration and client power was deemed more important than technological issues based on frequency. Cost remained in the top percentage of key themes as expected, whilst collaboration had decreased in significance along with behavioural change.

The two most important themes emerging from the interview data were supply chain integration and client power. The literature had been implicit in the importance of both themes but neither had been addressed to a great extent. There have been a number of studies detailing the applicability of various supply chain models to the construction industry (Vaidyanathan and Howell, 2007; love at al., 2009). Supply chain integration and engagement have also been studied as concepts in their own right (see Briscoe and Dainty, 2005; Bal et al., 2013). The notion of supply chain integration with specific regard to low carbon decision making and CO_2 emissions analysis continues to be elusive in the literature. The findings suggested that the industry is moving towards a supply chain approach to low carbon decision making, engaging supply chain actors (Jervis et al., 2014b). An indication of this movement was evident via an increase in awareness of the need for tracing the emissions back to the source, demonstrated by the following quotations:

> *'You've got to look back…to the manufacturers in terms of what information they are providing.' (Participant A1)*
>
> *'If you get primary data from your supply chain, you can go in and change it.' (Participant E1)*

The above evidence suggests that the industry is moving towards an understanding of how the supply chain could be used to aid the low carbon decision making process. By collecting information back from the chain the project team would find it easier to make low carbon decisions on the information given, indicating the importance of supply chain collaboration (Love et al., 1999). Love argues that in order for collaboration to be successful and enable the data sharing process to occur, organisational boundaries must be overcome through interdependencies. By implementing collaborative processes the supply chain could become a working strategy of symbiosis, moving away from individual jurisdictions and silos (O'brien et al., 2002; Abbott, 1988). Additionally, this has correlations with diffusion theory which is formulated on the basis of influential relationships. The construction industry is based on a series of relationships, not least with the client. It is these specific relationships which can

impact change and the spread of innovation in the industry (Dubois and Gadde, 2002; Miozzo and Derwick, 2002), indicating how low carbon decision making could diffuse.

Supply chain relationships are vital for information flow and influence between individuals. In cases where the relationship is weak greater impacts can be made, such connections have been coined as 'loose couplings' (Dubois and Gadde, 2002). Relationships in construction are often temporary and this can both encourage and discourage innovation. Greater collaborative processes could lead to weaker relationships having greater influence over future developments of a business and ultimately the diffusion of innovation; particularly if strategies are seen to be successful (Rogers, 1971; Gouwes and Reed van Oudtshoorn, 2011). These relationships are difficult to retain, therefore knowledge between 'loose couplings' can be lost (Songip et al., 2013; Blayse and Manley, 2004). One way to potentially overcome the difficulties with retaining relationships would be to address the supply chain from a different perspective by implementing networked structures (Cheng at al., 2001). A networked structure could encourage relationships to become fully formed. It could increase the impact of influence and encourage the diffusion of new low carbon strategies. The hierarchical supply chain structure placing the client as the key influencer in construction projects could also be broken down (Kilinc, Ozturkb and Yitmen, 2015).

The process of information sharing was supported in the literature and was found to be vital in securing a supply chain which is driven by demand, avoiding the distortions of the bullwhip affect (Forrester, 1961). It is demand which has sealed the fate of LCA processes as it has remained low. In order for the implementation of low carbon decision making strategies to occur, and more importantly, for them to diffuse, the power lies within the boundaries of influential relationships and supply chain integration which can encourage greater demand for products (Rogers, 1971). Acknowledgement of the benefits of integration further supports the view that collaborative processes encourage low carbon decision making strategies to diffuse through the chain. The acknowledgement of potential benefits of supply chain integration which specifically relates to CO_2 emissions is not widely found in in the literature. Emissions analyses have been carried out in several studies (Thormark, 2000; Menzies et al. 2007; Khasreen et al. 2009 and Buyle et al. 2013). All of which however, are technological in nature and disregard supply chain inputs and the importance of communicative processes in low carbon decision making.

The importance of client power became more evident as the research progressed. Client power was considered to be one of the most significant enablers and barriers to building sustainability. The client takes precedence in the supply chain, holding the greatest influence and power (Ahmed and Kangari, 1995; Ryd, 2014). Client power was found to impact on all other thematic codes either directly or indirectly. With the construction client holding such power the impetus is to take the lead from the top based on the traditional hierarchical and linear supply chain structures. (Rosinski et al., 2014; Dirix et al., 2013). If a client request is raised then others down the chain will follow, often due to the need to fulfil contracts and act on coercive institutional pressures (Cao, Li and Wang, 2014). The linear supply chain structure has been said to inhibit the ability to form influential relationships as each section has sole responsibility for individual tasks and there are no shared outputs (Cheng, et al., 2001; Kornelius and Wamelink, 1998).

Overall, the findings indicated that there was a strong movement towards human behavioural elements of carbon calculation; this was explicit in the data. Two of the most highly occurring themes were centred on human behavioural solutions to the emissions problem. Indirectly, BIM was also viewed as a behavioural solution due to the potential for collaboration networks (Hardin, 2011). These networks could aid the diffusion of low carbon decision making processes through the supply chain via information management and integration (Coelho and Novaes, 2008; Singh, et al., 2011). Although the literature implied its potential for use as a sustainability tool (Bynum, et al., 2012), it has stated that sustainable buildings are not at the forefront of BIM technology. It is primarily directed at efficiency which would ultimately decrease carbon by reducing waste. The notion of BIM as a 'process' for collaboration, not just a technology was a less developed area of research found in the literature although it was present (Singh, et al., 2011). BIM as a representation of technology was still important, but was much less significant than the literature suggested.

The content analysis highlighted the need to explain why an acknowledgement of human behavioural applications and generous levels of LCA tools, have not encouraged the wide scale development of low carbon decision making. Additionally it was also pertinent to use the content analysis to provide grounding to answer the research questions fully in chapter 6.0. It is of key importance to address what provides the impetus for constriction companies to become sustainable, how low carbon strategies can increase their legitimacy and how low carbon innovations can diffuse throughout an industry. The next section of this chapter evaluates the data via the application of two theoretical lenses: DiMaggio and Powell's

(1983) institutional theory and diffusion theory (Rogers, 1971). Each of the six key themes; supply chain structure, collaboration, client power, cost, risk and technology will be addressed using the theoretical lenses.

5.3 Isomorphic pressures and the diffusion of innovation

Empirical data was used to provide insight into how the three institutional isomorphic pressures (coercive, mimetic and normative) impact on the diffusion of low carbon innovation from a supply chain perspective. The importance of the client and the supply chain meant that approaching the research from a supply chain perspective was imperative. The criticality of this perspective was evident in the literature through studies such as Love, et al., (1999); Cheng, et al., (2001); Love, et al., (2004) which address the problems associated with uncoordinated and inefficient supply chains. The lack of supply chain coordination indicated a need to understand the potential pressures which may be imposed upon different sections of the supply chain. The three key pressures conceptualised from DiMaggio and Powell's 1983 institutional theory can be found in Table 5.1.

Table 5.1 Institutional theory: Isomorphic pressures

Isomorphic pressure	Description summary	Reference
Normative	Occurs when the informal social rules of an industry have influence over decisions.	(Winch, 2000)
Coercive	Derives from power and influence. It can also arise from formal and informal pressures exerted by organisations on other companies upon which they dependent. Additionally, it can occur due to cultural pressures.	(DiMaggio and Powell, 1983) (Prue and Devine, 2012)
Mimetic	Mimetic isomorphism works on the basis of companies imitating each other. Mimesis occurs generally during times of uncertainty.	(DeMaggio and Powell, 1983) (Moehler, et al., 2008)

Whilst institutional theory can be used to acknowledge the barriers placed upon the supply chain regarding low carbon decision strategies, the theory was found to be lacking in the discussion of how the pressures inhibit the uptake of innovative processes. The theory can explain how institutional pressures conceived from the drive to remain legitimate, adhere to social norms and meet legal requirements can fix industries into certain pathways. Institutional theory however does not provide theoretical insight into how these barriers can be overcome to stimulate change and adopt innovative strategy. Where theoretical gaps were discovered, the use of diffusion theory was applied in order to extend understanding into how isomorphic pressures inhibit or aid the diffusion of low carbon innovation. The key

components of diffusion theory used in this research, alongside theory foundations and adopter categories can be found in Table 5.2.

Table 5.2 Diffusion theory key components

	Description	Theory foundations	Adaptor categories	References
Diffusion theory	Diffusion theory can be used to explain how new innovations or work process can move throughout an industry. The key themes which underpin the concept of diffusion centre on collaboration, communication and personal influences. All three are essential for the diffusion of technology or new work processes to occur.	The innovation concept ↓ Diffusion process Personal influence ↓ The adoption process ↓ The roles of innovators and adopter categories ↓ The social system in which the diffusion fits	**Innovators** *(high risk takers, diverse social relationships, significant financial backing)* ↓ **Early Adopters** *(Highly integrated into social systems. Most likely to be consulted by potential innovation adopters)* ↓ **Early Majority** *(Reliance on informal information, take longer to adopt innovations)* ↓ **Late majority** *(Sceptical and cautious acceptance of peers is vital to their adoption)* ↓ **Laggards** *(Slow to adopt, aversion to change low finance, traditional)*	(Rogers, 1971) (Gouwes and Reed van Oudtshoorn, 2011) (Koester and Lustig, 2011) (Fill, 2005)

In order to illustrate the way in which these two theories will be used together Figure 5.1 was configured. The Institutional diffusion wheel highlights how Rogers, (1971) diffusion theory has been used to overlay DiMaggio and Powell's, (1983) institutional theory in the context of supply chains.

Figure 5.1 Institutional diffusion wheel for low carbon innovation

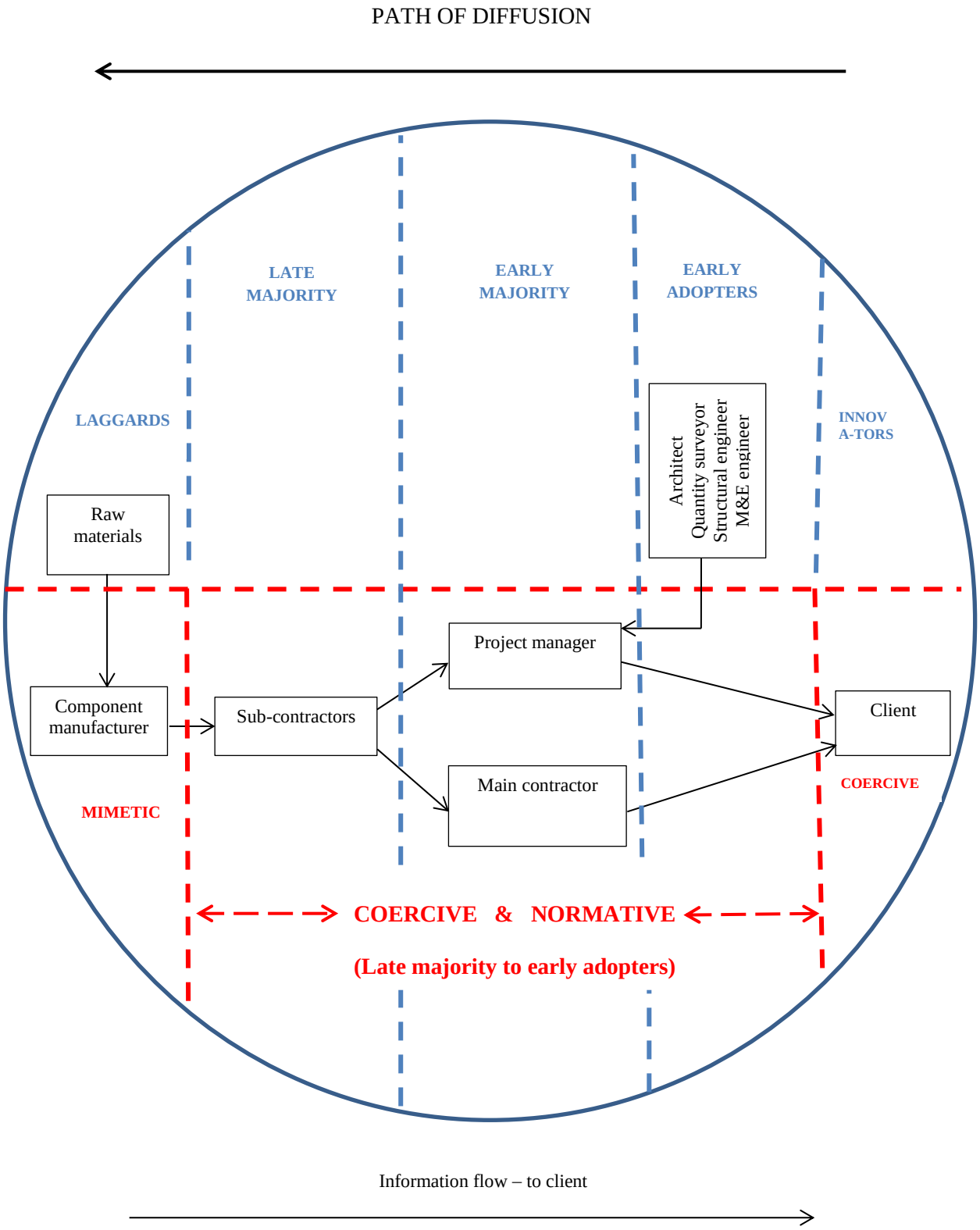


Figure 5.1 was developed to aid the construction of the new supply chain framework (Figure 5.2). The institutional diffusion wheel for low carbon innovation provides an illustration of the key institutional pressures that each supply chain actor is most subjected to. It also assesses how these institutional pressures align with the adopter categories in the diffusion process. The development of this wheel enabled these concepts to be taken into account for the development of the final framework. For example, the adopter category of the client as an innovator means that they must be central; however it also provides an awareness of the restraints placed on clients through coercive pressures. Acknowledgement of this enabled the positioning of the client to be carried out, whilst taking into account their influence over innovation and the barriers they need to surmount in order to become innovative clients. Additionally, the pressures clients are exposed to inhibit them from taking risks on innovative products. Therefore as the innovator in the diffusion process, the environment in which they implement sustainability must feel financially safe i.e. a system built on the collective and not on self-protection and competition.

Figure 5.1 also highlights the pressures which other supply chain actors are exposed to alongside their diffusion adopter categories. The design team are primarily subjected to normative and coercive pressures from the client who can act as a barrier to innovation by exerting hierarchical authority over them. The supply chain strives to adhere to client demands to ensure that they do not lose contracts, following traditional construction procedures is thought to eliminate this risk (Blayse and Manley, 2004). In eliminating the risk of applying innovative procedures, client power prevents the implementation of novel practices as the supply chain strives to fulfil client requirements; thus the client acts as a barrier to low carbon innovation. As the first to have contact with the client, the design team are considered as the early adopters for innovation. Most innovation begins at the design stage, the point at which most collaboration occurs in current supply chain formats (Basbagill et al., 2013). Collaboration is considered a key component of diffusion theory and a significant diffusion enabler (Rogers, 1971). As a result of isomorphic pressure placed on the design team they are considered to be early adopters because of their supply chain position.

The early majority in the diffusion of innovation adopter categories was found to be the management team consisting of the project manager and the main contractor. They were also subjected primarily to normative and coercive pressures which are fed down from the client and design team. In order to be selected for contracts, the management team would be required to adhere to expected social norms in order to remain legitimate (Barreto and Baden-

Fuller 2006). Additionally, main contractors will often work with architects many times on different projects, building influential relationships which are essential for the diffusion of innovation (Gatignon and Robertson, 1985). When these relationships become influential, particular ways of working become ingrained in work strategies. These strategies become the social norm between supply chain actors and are secured with normative pressures (Dillard, et al., 2004).

The late majority and laggards are considered to be the lower section of the chain, moving further away from client influence. Consequently these supply chain sections are the most difficult to reach. A high proportion of those working in construction are sub-contractors with up to 90 percent of work being carried out by sub-contracted teams (Ayalp and Ocal, 2014; Clough and Sears, 1994; Hinze and Tracey, 1994). Sub-contractors are generally smaller companies who do not have the freedom and high risk tolerance due to the competitive nature of the industry (Martins and Terblanche, 2003; Steele and Murray, 2004). In view of this they are unlikely to innovate but are likely to react to isomorphic pressures placed on them by higher ranks in the supply chain in order to remain competitive. They are however late to adopt new strategies. The laggards in this supply chain system are considered to be those who are far removed from the client such as raw material extractors and manufacturers. Considered as sectors in their own right, they are more likely to comply with their own regulation such as manufacturing regulations rather than those enforced specifically from the construction industry. Additionally studies have argued that manufacturing sectors are not at the forefront of environmental control due to the notion that regulation adversely affects business (Rubashkina, Galeotti and Verdolini, 2015). Despite this, in order to maintain construction contracts in a new system, manufacturing companies would need to provide some evidence of environmental alacrity in order to remain positive in the component selection process. It is thought that the manufacturers and raw materials extractors are highly likely to be influenced by others in their social network at this stage (Rogers, 1971; Gatignon and Robertson, 1985; Gouwes and Reed van Oudtshoorn, 2011). A reason for social influence is the financial constraints experienced by manufactures. They are more likely to take on innovation as a result of mimetic pressure as this eliminates research and development costs incurred through innovative production modification which may or may not be successful (Rubashkina, Galeotti and Verdolini, 2015; Sarrina Li and Lee, 2010).

Analysis of the findings was carried out via the overlaying the two theories which provide understanding surrounding the impact of institutional pressures and the diffusion of low

carbon innovation. The structure of the analysis will enable the discussion to move throughout the findings to provide answers to how low carbon decision making strategies can be diffused effectively via collaboration, supply chain integration, and client led approaches.

5.4 Institutional isomorphic pressures

5.4.1 Normative pressures

Normative pressures occur as a result of social pressure exerted on an industry which cause them to behave in particular ways (Deephouse, 1996).The associated pressures are generally acknowledged to come from sources such as trade and professional associations (Bhakoo and Choi, 2013). Empirical evidence from studies such as Khalifa and Davidson, (2006) and Bhakoo and Choi, (2013) has shown that normative pressures can also derive from the supply chain itself in the form of suppliers and customers. The evidence for normative pressures can be found in traditional structures in the construction industry; the linear format of the supply chain for instance and design build contracts (Xia et al., 2013). Traditional methods of construction practice are not enforced by legislative rules but are expected and kept in place by informal social norms encouraged through isomorphic pressure (DiMaggio and Powell, 1983; Moehler et al. 2008).

Low carbon decision making analyses are generally carried out post-construction as this is the expected norm. Retrospective analyses make obtaining information from the supply chain difficult, particularly as the supply chain is linear in nature (Poudelet et al., 2012). Technological analyses are the norm and are thought to be a normative pressure which inhibits the development of a low carbon decision making process by excluding behavioural considerations. The retrospective nature of calculation, lack of collaboration and focus on client power are social norms which can inhibit the diffusion of low carbon innovation. Firms do not want to be seen to be stepping away from these norms and lose legitimacy (Barreto and Baden-Fuller, 2006). Normative pressures are thought to be prevalent in UK construction due to the development of professional systems which people do not want to act outside of (Moehler et al., 2008; Winch, 2000).

5.4.2 Coercive pressures

Coercive isomorphism derives from power and influence; it is also the result of formal and informal pressures which are often forced upon companies by other organisations on which they are reliant (DiMaggio and Powell, 1983). They can often occur as a response to governmental or legislative standards and sometimes overarching pressures such as costs. They can also occur as a result of cultural pressures within an industry. An example of coercive pressure was the Construction Skills Certification Scheme (Prue and Devine, 2012). There was significant evidence of coercive pressures in the empirical findings of this study which have impacted the development of low carbon decision making.

5.4.3 Mimetic pressures

Mimetic isomorphism occurs when companies mimic other companies which they deem to be successful in their own social set (DiMaggio and Powell, 1983). The primary reason for the occurrence of mimesis is business uncertainty. When potentially innovative solutions are not understood fully and the goals of an organisation are ambiguous, companies will mimic others of a similar status and size (DiMaggio and Powell, 1983). They use the success of other businesses as a benchmark, limiting the perceived risk of implementing new strategies or innovations (Zsidisin et al., 2005). By mimicking others' solutions to problems they aim to seek legitimacy and to compete with those companies as they fear being left behind (Bhakoo and Choi, 2011). The concept of legitimacy is important to this institutional pressure as legitimacy proves business worth (Barreto and Baden-Fuller, 2006). It is particularly relevant when solutions are unclear which has been the case with the lack of low carbon development (Prue and Devine, 2012; Cyert and March, 1963). One of the current failings of low carbon construction is that the measurement of CO_2 it is not currently considered as a requirement for legitimacy. It is in the most part considered as an additional cost which is avoided. Evidence of all three isomorphic pressures was evident in the findings and their application to thematic analysis is explored in the subsequent sections.

5.5 <u>Institutional pressure impacts on the diffusion of innovation</u>

5.5.1 Supply chain structure: Integration and communication

The findings from the interview data suggested that the supply chain was imperative in the construction industry for emissions analysis, beneficial for tracking carbon outputs

throughout the project lifecycle (Kurul et al., 2012). The current analysis drivers have been technology focussed which has been motivated by individual firms, most likely due to forward thinking clients' requirement for retrospective carbon analyses (Poudelet et al., 2012). Consequently, due to lack of LCA demand and the limited pressures which encourage data sharing throughout the chain, the benefits of supply chain integration and collaboration have been missed. The empirical data has indicated that the lack of supply chain based understanding of carbon emissions may be a result of the current supply chain structure (Koh et al., 2013). The evidence for beneficial supply chain integration and engagement was apparent in the findings due to the frequency of supply chain references. In view of the importance of data sharing it became clear that there must be an understanding of why decision making processes are not integrated. Attention was often given to the supply chain being fragmented (Cheng, et al., 2001). The division of tasks are held in place by the traditional supply chain structure which is considered as a barrier to sustainability as supported by the following quotations:

> *'We need to buy from our supply chain and so we need that information and maybe it's our lack of understanding of how to go about asking that from them that's the problem.' (Architect, supply chain position 3)*
>
> *'Separation of duties actually can make it harder to design an environmental building because you've got to get more people on board to agree.' (Architect, supply chain position 3)*
>
> *'I think supply chains are a very big ... in what I've just said there, supply chain agenda is huge, on so many different aspects because you're upstream impact could be so much more significant than the focus that we've had in recent years.' (Mechanical and electrical contractor, supply chain position 3)*
>
> *'I think the problem is the construction project is made up of loads of part…there's too many bits I suspect.' (Client, supply chain position 6)*

The supply chain has been in its current form for many years, and the traditional linear format is still widely used (Cartlidge, 2009). Many other formats have been discussed in terms of efficiency improvements such as the E-business model and maturity model (Lee and Whang, 2001; Vaidyanathan and Howell, 2007), but no new systems have been put in place. The continued use of linear structures has been considered as a normative pressure inhibiting the development of low carbon decision making via power dichotomies and fragmentation which is considered as the norm (Cheng, et al., 2001; Kornelius and Wamelink, 1998).

The fragmented supply chain was found to be a critical issue for CO_2 data sharing and emissions analysis. Tasks within linear chains were found to be divided up into individual

disciplines which were considered singularly, without understanding the impacts which may resonate throughout the supply chain (Korneleus and Wamelink, 1998; Cheng, et al. 2001). The individuality of each supply chain actor created guarded attitudes towards data sharing and understanding which is considered to be a normative action. These attitudes have made sharing information problematic as CO_2 data interpretation can be fraught with difficulties (Rajendran, 2001). The dichotomous nature of the construction supply chain has suggested a need for increased collaboration and integrative processes to play a role in the future development of sustainability practices. Data from all components of the supply chain must be assessed equally and to the same standards, avoiding subjectivity and enforcing the potential benefits of networked supply chains (Cheng et al., 2001). The problem of subjectivity has been particularly relevant for current LCA methods due to scope and boundary issues surrounding carbon calculation and methodological differences (Dixit et al., 2013; Yang et al., 2013). If decisions could be made from the conception of the project via supply chain networks, low carbon decisions could be made more easily and low carbon strategies could diffuse between supply chain actors.

5.5.2 Supply chain structure: Collaborative relationships

The complex nature of emissions analysis highlighted the importance of relationships within the supply chain. Relationships may aid low carbon decision making particularly with sustainability as it often requires a multidisciplinary knowledge base (Kiker et al., 2013). The linear supply chain configuration has inhibited the development of relationships as the structure encourages the division of the supply chain into individual components (Korneleus and Wamelink, 1998). The most significant issue is that there are singular objectives which are personal to each actor (Cheng, et al., 2001). They each make decisions for their own benefits. The linear model encourages the fragmentation process as it discourages coordination and communication (Cheng, et al., 2001). The lack of such processes may provide a reason why environmental assessments are usually carried out retrospectively. The data gathering process from the conception of the project may be considered too difficult as data is unobtainable due to normative supply chain structures segregating supply chain actors (Poudelet, et al., 2012). Individuality of each supply chain section and the retrospective environmental analysis was supported by the following quotations:

> *'If I'm selling plasterboard that's all I'm really interested in. Do I care which wire you put to it no…There's too many vested interests…I think clients can sometimes pull*

it all … but individually there's too many components.' (Client, supply chain position 6)

'At an early stage you don't know the full make-up of the building, and so therefore you don't do the analysis and you wait until the end of the building, when it's completed, then you go, there's my analysis, at which point it's too late to actually change anything.' (Mechanical and electrical contractor, supply chain position 3)

Separation of duties is a normative pressure as it is not enforced but has become part of the traditional procedure for building construction (Korneleus and Wamelink, 1998). The literature on construction supply chains has highlighted the difficulties associated with information gathering and sharing (Cheng et al., 2001). The separation of duties as highlighted by the quotations above suggests that there is no shared responsibility for the project as others focus on their designated tasks. Love's (1999) argument that uncoordinated and dysfunctional supply chains make the dissemination of information difficult and increased conflict is evident in the empirical data. The potential for increased collaboration and conflict resolution was also addressed in the interview findings:

'We need to buy from our supply chain and so we need that information' and maybe it's our lack of understanding of how to go about asking that from them that's the problem.' (Architect, Supply chain position 3)

'Separation of duties actually can make it harder to design an environmental building because you've got to get more people on board to agree with that policy. If there's fewer people and they all agree it'll go ahead. If there's a larger group and most agree but one disagrees, you still might not go forward with the solution to get a much more environmental building at the cost of, say, 1% extra of the building.' (Architect, supply chain position 3)

The findings outlined that information is required from different sections of the supply chain, meaning that data sharing on products and processes would be required regarding CO_2 outputs. The data and the literature provided evidence that there were difficulties associated with tracing carbon outputs due to embodied impacts (Crishna et al., 2011). The need for carbon tracing necessitates further confirmation of a requirement for increased communicative processes and collaborative work via the supply chain. A collaborative application could theoretically aid low carbon decision making via data sharing (Cheng, et al., 2001; Love, et al., 2004). The findings supported the perception of the linear format of the supply chain as a sustainability barrier in terms of coordinating agreements on sustainable buildings. The literature highlighted that the structure of the chain inhibits data flow disabling

sustainability assessments as facts and data are not freely available (Akintoye, et al., 2000; O'brien, et al., 2002; Rodriguez-Melo and Mansouri, 2011).

Integrating the supply chain and engaging supply chain actors in communicative processes could increase carbon awareness. Awareness would enable people to agree on new terms and strategies. Improved information exchange could encourage problem solving through cooperative understanding and development (Ayuso et al., 2011; Bal et al., 2013). Integration and engagement of the supply chain was also supported by Figures 4.7 to 4.10. Each supply chain reconfiguration favoured increased engagement. One of the potential solutions to the current lack of collaborative engagement would be to introduce a network supply chain approach, whereby greater communication, engagement and integration levels can be achieved. Embracing the concepts of collaboration and flexibility could support the dissemination of carbon data in order for more informed low carbon decisions to be made (Crowley and Karim, 1995; Love, et al., 1999; Cheng, et al., 2001; Love, et al., 2004). The implementation of new systems is expected to be problematic and difficult because of the normative pressures at force. Traditional supply chain norms encourage a continuation of the linear supply chain model. It can be argued that these pressures have secured the use of retrospective analyses in carbon calculation due to the construction industry's focus on maintaining legitimacy through socially normative pressures.

The evidence suggested that the most challenging point of supply chain integration was referred to as supply chain 'silos' –

> *'Working together…the business isn't used to doing that…it's used to working in its own little silo.' (Participant C1, focus group)*

The individual performance of supply chain actors was considered to be an inhibitor of information flow. Working in silos encourages the retainment of normative social and cultural barriers, as people remain solely in control of their own individual tasks (Abbott, 1988). Furthermore, the impact of construction contracts on the supply chain was also proven to be an inhibiting coercive pressure working against supply chain integration. The majority of construction contracts are design – build contracts (Wigglesworth, 2012), evidenced by the following data:

> *'I think it's about 80% of projects in the UK are done on a design and build so, design and build, the consultant will write a set of performance criteria.' It will then go to*

five/six tendering main contractors, who will then go to their supply chain.' (Mechanical and electrical contractor, supply chain position 3)

Participants argued that by the time the project was tendered, particularly from the mechanical and electrical standpoint, many decisions regarding sustainability had been made and so influence was minimal. These coercive pressures of contractual obligation provide an understanding of why retrospective analysis had been relied upon. The ease of implementing a technology post construction without widespread understanding suited the structure of construction projects.

If linear supply chain structures remain in place there is no impetus for improving collaborative relationships. The impact of normative pressures will maintain the structures holding traditional low collaboration processes in place (Cheng, et al., 2001; Kornelius and Wamelink, 1998). Lack of supply chain integration which has been secured by institutional pressures has theoretically inhibited the diffusion of low carbon innovation. One of the key drivers of diffusion theory is the importance of collaboration and communication which encourages innovation to become a social norm through the expansion of social groups (Rogers, 1971). In order for low carbon decision making to become a social norm, active engagement throughout the supply chain would be required. If this occurred, influential relationships could be formed more easily and the use of new processes could be adopted. It is the strength of influential supply chain relationships which encourages the greatest change as they inspire supply chain actors to seek legitimacy by searching for similar outcomes (Dubois and Gadde, 2002; Miozzo and Dewick, 2002). Furthermore the requirement of 'top down' innovation from the client institutionally secured by hierarchical supply chain structures furthers the potential application of networked supply chains. By increasing networked systems more power would be given to other supply chain actors to influence sustainability outcomes by transcending normative pressure barriers (Cheng et al., 2001).

5.5.3 The construction supply chain: Encouraging behavioural change

The literature highlighted that behavioural change can have a significant impact on sustainability (Janda, 2011). The primary impetus for such change was found to be knowledge acquisition and retention (McKenzie-Mohr, 2000). Knowledge enhancement however, is not always effective enough to spur sustainability into action as enhancing knowledge has not always been successful in the attainment of sustainability goals (Geller, 1981; Finger, 1994). It can be argued that social norms inhibit the development and distribution of knowledge if for example the supply chain structure inhibits collaborative

partnerships (Cheng et al. 2001). Furthermore, the short term contracts associated with construction projects create dysfunctional organisational memory, making behaviour change difficult. The archetypal notion of each construction project as a unique entity makes knowledge retention problematic (Dubois and Gadde, 2002; Blayse and Manley, 2004). Consequently short term contracts and poor knowledge acquisition hinders learning (Barlow, 2000). In turn, socially normative pressures continue to inhibit the development of learning and knowledge, thus impeding the diffusion of innovative low carbon strategy.

It is difficult for new concepts such as low carbon decision making processes to become a normative pressure as social norms are ingrained over time and do allow new concepts to become established easily. Often new ideas are slow to make significant inroads into traditional low-innovation industries (Songip et al., 2013). Theoretically it is highly likely that devoid of heavily enforced legislative drivers, new low carbon construction methods could take a long period of time to develop as a normative pressure. In essence the empirical evidence suggests that the most efficient way to promote novel ideas is to encourage mimetic legitimacy via the diffusion of innovation; achievable through supply chain actors working in close proximity.

The impact that normative pressures can have on the diffusion of innovation is interesting, particularly in relation to knowledge acquisition and behavioural change. Often, pressures which encourage social norms make change difficult, particularly in high risk and low innovation businesses (Abderisak and Lindahl, 2015; Songip et al., 2013). The view that shared learning is required in order for the diffusion of innovation to take place is of key importance in this research. Normative pressures realistically occur as a result of a shared learning environment (Peansupap and Walker, 2005). Shared learning is critical for diffusion which relies on communication and dissemination of information (Rogers, 1971; Gatignon and Robertson, 1985). Industries adhere to the social norms of their particular social group and conform to them in order to remain legitimate.

Once knowledge is acquired it is retained through repetition and often companies will conform to social norms due to institutional pressures compelling them to (DiMaggio and Powell, 1983). In this instance mimetic pressures are also relevant in ensuring low carbon innovation diffusion as companies will mimic each other in order to remain legitimate in times of uncertainty (Bhakoo and Choi, 2013). If normative pressure exerted on the chain does not allow for the flow of new concepts then they forever remain on the outside of social

norms making diffusion difficult. Therefore initial steps toward innovative concepts must begin with behavioural change; however normative pressures can hinder the behavioural development as explored in the following quotation:

> *'I don't pay the bills, I'll leave the lights on, leave the water on, leave the air conditioning on, so we have got to get a massive change in peoples mind-sets so they take responsibility.' (Client, supply chain position 6)*
>
> *'I think human beings inherently will always try and get round the problem or solve a problem to their best advantage, so there is a behavioural thing there and, you know, if everyone wanted to save the environment, I think we'd be in a totally different position. (Main contractor, supply chain position 4)*

Normative pressures have encouraged negative behaviour regarding sustainability. For example, people leave lights on, leave engines running and fail to recycle without environmental consideration even when it is economically detrimental (Janda, 2011). As people exhibit the attitudes and actions of others, one person leaving an engine running will often translate into many people displaying the same behaviour (Janda, 2011). Many reject environmental consequences and so therefore other elements of construction have been seen as more important such as risk and cost (Abanda et al., 2013). In the long term, focus on these core elements may be short sighted as resources deplete, costs increase and the built environmental requires adaptation to climatic change (Sanders and Phillipson, 2003). Technological solutions have often been seen as an additional quick fix to the problem of increasing emissions should the client require it (Baek et al., 2013). The importance of construction risk and cost over environmental issues has been driven by coercive institutional pressures such as contractual obligations, directly impacting on the diffusion of innovation.

5.5.4 The construction supply chain: Existing coercive pressures

Evidence of coercive pressures which are already being exerted on the supply chain in its current format was found in the form of Environmental Product Declarations (EPDs). Their establishment has overcome the reliance on cost and competition for certain companies. The aim was to encourage supply chain actors to adhere to certain standards. Tata Steel for example generates EPDs for their supply chain partners. The EPD process encourages good supply chain relationships as the issued EPDs can give partners a competitive edge as they are freely available to use them for other clients. A win-win situation can be created providing positive outcomes for the supply chain and clients whilst furthering sustainability (Jervis, 2015; Tata Steel, 2012). The use of this system is a forward thinking arrangement

which provides evidence that being competitive does not solely rely on cost driven prospects (Rodriguez-Melo and Mansouri, 2011). Companies using this scheme were coerced into implementing EPDs in order to be selected for work. EPDs were discussed in the findings as a way for companies to declare their supply chain impacts:

> *'There's a … umm … I can't remember if it's a guidance note or a policy, but there's something called … I think we've mentioned it in the past, the Environmental Performance Directive I think it's called, EPD, yes, so every product needs to declare … I think it was 2013 it came in, Environmental Product Declaration, so as part of that, every manufacturer of a product that's used in the construction industry must declare their supply chain impacts for that product, so if it was a concrete beam, the company would have to give an EPD on that beam.' (Mechanical and electrical engineer, supply chain position 3)*

EPDs act as a coercive pressure for companies who choose to implement them. Supply chain actors must provide an environmental declaration to advise of supply chain impacts in order to be included in the contract (Bovea, Ibáñez- forés and Agustí- Juan, 2014). Interestingly the findings above showed that the participant was not fully aware of whether declarations were considered as guidance or policy for the company. In the case of declarations the current structure of the supply chain has not inhibited their development which is testament to their increasing use across Europe (Passer et al., 2015). Their application however remains optional. The impact of EPDs could provide a positive step towards collaborative supply chain processes as information provided by each supply chain actor is a requirement which would deliver a need for communicative processes (Zackrisson et al., 2008). Increased communication flow would aid data and information sharing, increasing understanding which could be secured by the implementation of declarations (Persson and Orlander, 2004; Jeffrey, 2009). The participant using EPDs was considered a market leader in the field, a company with whom others would strive to work with. In this instance other supply chain actors would initiate steps towards implementing environmental declarations in order to appear legitimate and win work on large contracts. The level of expectation can ultimately be viewed as a positive coercive pressure as there would be a specific and most likely a contractual requirement to declare environmental impacts.

5.5.5 Supply chain structure: The impact of mimetic pressure

Having discussed normative and coercive pressures exerted on the construction supply chain which could aid or inhibit the diffusion of low carbon innovation, the findings were scoured for evidence of mimetic isomorphic pressure. There was a lack of significant evidence in the findings suggesting that mimetic pressure was particularly impactful on supply chain

outcomes. The structure does not allow for mimetic pressure to be particularly effectual when encouraging widespread uptake of new methods and strategies, primarily due to compartmentalisation (Cheng et al., 2001). The structure provides no stimulation for collaboration and communication and companies are able to shield new developments (Cheng, et al., 2001; Kornelius and Wamelink, 1998). In turn, the reticence of the supply chain makes it difficult for imitation to occur. Imitation is required for the diffusion of innovation; people view success and wish to emulate it (Rogers, 1971).

The diffusion of innovation advocates the importance of relationships in spreading novel concepts (Rogers, 1971; Gatignon and Robertson, 1985). The imitation factor however cannot be overlooked as the current format of construction projects dictates that relationships are short- term (Songip et al., 2013). Short term relationships affect information sharing and retention which is arguably held in place by current supply chain structures. In order for diffusion to take place an innovation must occur and others must try to rival the success through implementing the same systems or products (Rogers, 1971). As more people adopt a new concept a critical mass is reached, the point at which enough people are using the product in order for it to sustain itself (Mahler and Rogers, 1999). At this point the risk of implementation is reduced; the imitation factor can aid the development of a product as each individual in the system makes their own adoption decisions (Gouws and Rheede van Oudtshoorn, 2011). Decisions on adoption are highly likely to be influenced by other companies (DiMaggio and Powell, 1983; Cao, Li and Wang, 2014). The imitation factor could provide a useful tool for the diffusion of new products (Markus, 1987; Mahler and Rogers, 1999) which could occur through supply chain actors working in close proximity.

The above examples provide evidence of the usefulness of using both institutional theory and diffusion theory in conjunction. Isomorphic pressures can only illustrate the power of the institution and how it affects the way industries behave. It does not address how these pressures can impact on the diffusion of innovation or how these pressure barriers can be overcome. A defining factor of diffusing novel concepts is collaboration and influential relationships. The impact that institutional pressures have on collaboration in the construction industry and the effect this has on the diffusion of innovation is explored below.

5.6 Collaboration

A case for creating increased collaborative networks with regards to low carbon decision making has been a product of the literature and empirical data in this research. Influential

relationships through collaboration have been shown to facilitate support for low carbon decision making practices (Persson and Orlander, 2004). Communication flow among supply chain actors is considered essential for the diffusion of low carbon strategies and information management in construction projects (Coelho and Novaes, 2008; Singh, et al., 2011; Jeffrey, 2009). Collaborative relationships across supply chains between organisations have been proven to progress with increased information exchange (Zhang and Dhaliwal, 2009). It can be argued that the level of communication is dictated firstly by client engagement and secondly the supply chain structure which are institutional coercive pressures faced by construction companies. The data highlighted that collaborative processes were impacted primarily by mimetic pressures but evidence of normative and coercive pressures were also found.

The empirical findings highlighted that it is not justifiable to suggest that the construction industry does not collaborate as those within in the industry stressed that it does occur, and a lack of involvement was frowned upon. It was expressed however that this engagement was often at a minimum and in line only with what was expected, indicating the impact of normative pressures on the collaborative process. Current collaborative expectations were indicative of normative institutional pressure, as often those involved in construction projects will not go beyond expectations or social norms. A similar attitude towards carbon emissions was also found. These pressures would need to be overcome in order to apply collaboration to CO_2 data sharing. Collaboration in the context of emissions however could be seen as a standard progression, due to the high level of data requirement for calculation (Fay and Trelaor 1998; Liu et al. 2012; Dixit et al. 2012).

As sustainability or CO_2 analyses are generally carried out retrospectively via technological means, collaboration is not a requirement for analysis (Poudelet et al., 2012). The social norm is to complete analyses via mathematical methods which act as normative institutional pressures, inhibiting the development of collaboration. By not providing the necessity for increased collaboration, a barrier to diffusion has formed as those who require carbon calculation will simply use currently available methods for ease. Collaboration traditionally occurs at a minimal level and only frequently at the very beginning of a project (Basbagill et al., 2013). In order to provide a method of engagement for carbon emissions throughout the project the expansion of communicative processes must occur.

The notion of joint working could be an important factor in the development and diffusion of low carbon processes. Although dismissed by some as an unrealistic and idealised idea, some forward-thinking sustainability-focussed firms are seeking to implement sustainability as best practice via joint working, which has proven to be successful. Examples of this have been found in public-private sector collaboration projects which have used novel procurement methods to group the best skills and resources from both sectors for infrastructure projects (Adetola et al., 2011). The acknowledgement of the benefits of skill sharing has led to the emergence of public Private partnerships (PPP) (Li and Akintoye, 2003). A further example can be found with the implementation of Environmental Product Declarations at Tata Steel (Tata Steel, 2012; Jervis, 2015).

The findings highlight a leaning towards joint working in order to implement low carbon decision-making. One of the core failings found was the inability to share information and the institutional pressures that prevent those in the supply chain from progressing together i.e.

> *'I think there's a lot of good work going on. A lot of people are pushing forward with it.' (Mechanical and electrical engineer, supply chain position 3)*
>
> *[BIM] 'That's what we're thinking of having … it is helping with the collaboration between all parties…not every company is on the same learning curve as what others are, not at the same point in the learning curve..' (Mechanical and electrical engineer, supply chain position 3)*

Collaborative processes were found to generate mimetic pressure throughout the construction supply chain. The pressure to behave in similar ways to others could encourage collaborative processes, inspiring others to share information on carbon data (Love et al., 1999; Cheng et al., 2001; Love et al., 2004). Additionally, the implementation of innovative low carbon products provides greater possibilities of diffusing novel low carbon concepts throughout the supply chain. If pressures were placed on supply chain actors to implement low carbon strategy via collaborative processes, mimetic pressures could become highly relevant for diffusion (Rogers, 1971).

Through greater collaboration, success can be viewed and others will endeavour to seek the same success in order to remain legitimate through socially constructed systems (Barreto and Baden-Fuller 2006). Mimetic pressures felt through collaborative systems could potentially speed up the process of the diffusion of innovation as new systems or strategies could reach greater numbers of people quickly (Rogers, 1971). The benefits of collaboration are already widely acknowledged in supply chain literature but not necessarily specific to carbon

analyses (Lin et al., 2002; Cheng et al., 2001; Love et al., 2004). The application of the benefits of collaborative processes in construction could form an essential component of integration and information management (Coelho and Novaes, 2008; Singh et al., 2011).

The implementation of collaborative networks in construction projects could heighten the impact of mimetic pressures as new models create uncertainty (Prue and Devine, 2012). Uncertainty could encourage supply chain actors to seek involvement in new systems in order to maintain legitimacy, particularly if the success of a project is viewed. The critical success factor for collaboration and its application to low carbon strategy is its use from the conception of construction projects. Participants were mindful of the potential for the early implementation of collaborative processes as illustrated below:

> *'It's better if all projects … all parties in the project are involved at an early stage so they can have that input and collaborate between each other.' (Mechanical and electrical engineer, supply chain position 3)*

Implementing a collaborative platform whereby supply chain actors are involved in collaboration processes from the commencement of the project has been promoted as a solution for increasing collaborative networks. If a viewed collaboration platform was integrated on projects, other supply chain actors would feel inclined to ensure they were giving and receiving all of the required information to maintain legitimacy. Numbers conforming would increase as a network of peers develops (Haunschild, 1993). Mimetic and normative pressures encourage the diffusion of low carbon innovation as success is acknowledged and new concepts are proliferated through fear of losing legitimacy. Mimesis occurs until pressures to conform become normative as collaboration becomes the social norm. The following quotations illustrate the influence of visual success in the implementation of innovative processes:

> *'I do like the collaboration kind of world because you do build partnerships up, you do see … other people's ideas come forward…if you've got that collaboration … that true collaboration in there and you're listening to people's ideas, you're listening to people that view things slightly differently, then you can get to a good solution.' (Client, supply chain position 6)*

Increased collaboration was found to have a positive effect on the whole construction process. In collaborative systems the implementation of new ideas could be tested and shared thus reducing risk (Toole, 1998). The reduction of risk is an important component of the diffusion of innovation. If perceived risks are reduced, greater numbers of people are much

more likely to take on new strategies and products. Individuality of supply chain actors inhibits collaboration which restricts the possibility of others viewing success (Crowley and Karim, 1995). In closer proximity, there is greater opportunity for mimetic influence as supply chain actors strive to become valid players in construction projects.

The implementation of network supply chains could increase collaborative networks exerting greater mimetic pressures on the supply chain, acting as a driver for change and diffusing new concepts and strategies through the encouragement of greater adoption (Cheng et al., 2001; Greenwood and Hunings, 1996). A networked system could eliminate competition drivers, determined by individual jurisdictions, opening up the channels of communication and shared responsibility which are all essential factors for innovation diffusion (Rogers, 1971). Network approaches embrace cohesiveness, communication and flexibility which could aid the diffusion of low carbon decision making strategies at low cost, without the need for intensive technological investment (Love et al., 1999; Cheng et al., 2001; Love et al., 2004).

5.6.1 Changing behaviour through collaborative approaches

The implementation of new low carbon decision making strategies requires behavioural change as a movement away from the norm ensues. For example, those down the chain must feel that they can influence the client which would require novel supply chain systems of collaboration and behaviour modification (Cheng et al., 2001). Enhanced collaboration could be achieved through mimetic pressure. A further supply chain model capable of achieving cooperative behaviour can be found in the maturation supply chain model which can reduce conflicts and promote output consistency. The problem found with this model is that it propitiates institutionalisation and so therefore the use of this model may make future changes difficult. The success of diffusion using this model could derive from mimetic pressure (McCormack and Johnson, 2001; Vaidyanathan and Howell, 2007).

As discussed one of the core reasons for the occurrence of mimetic isomorphic pressure is risk potential. Mimicking others is thought to eliminate risk by acknowledging success and eradicating the need to outlay costs on an innovation which may fail. Businesses that are seen to be successful will be imitated (DiMaggio and Powell, 1983). The core reasoning behind imitation is that it significantly reduces search costs and collective knowledge is a positive way of exploring an innovation without having the required knowledge within the company (Sarrina Li and Lee, 2010; Brouthers, O'Donnell and Hasjimarcou, 2005).

In industries which experience high risk contracts, frequent uncertainty encourages them to feel the force of mimetic pressure. Imitation is accepted with much more confidence than simply forging ahead with unknown innovation (Deephouse, 1996). Imitation is acknowledged as a legitimate solution to uncertainty (Massini, Lewin and Greve, 2005). Calculation of CO_2 emissions in the industry is understandably considered as an uncertain and risky task. With low demand, and high levels of data collection technology in a saturated market, implementing unknown low carbon strategies with high cost is seen as a high risk (Toole, 1998). Risk was a strong theme running throughout the findings:

> *'Innovation is risky and that's why you wait for someone else to take the risk often, unless you are one of those innovators, and then when it looks like it's okay, then other people take it up, so …' (Mechanical and electrical engineer, supply chain position 3)*

> *'I mean if there's a way of … there is no way of reducing the risk with innovative stuff, other than to do it, and test it and see what happens I guess.' (Main contractor, supply chain position 4)*

Innovative processes must lead to profitability and this is mostly determined by past success (Songip et al., 2013). Much of the existing technology for CO_2 calculation has suffered from poor uptake rates or is simply not required once purchased. The similarity of products had provided potential reasoning behind these poor uptake rates (Gatignon and Robertson, 1985), which has led to those within construction to mimic the inertia towards response to the emissions problem. Past failures have directed the industry away from carbon measurement. In order to break this cycle, new successful methods would need to be implemented and expressed through homophilous and heterophilous communication channels in order to acquire widespread diffusion via influential pathways (Gatignon and Robertson, 1985). Often it is those who remain within their social group that do not innovate as the findings suggest:

> *'It often is down to personal relationships as well, there's an existing personal relationship and so we'll stick with these people, or it's they've heard that this company is difficult, or this bit of technology doesn't work and they don't want to risk' (Main contractor, supply chain position 4)*

Without exposure to new companies who may be overtly innovative in CO_2 emissions analysis, success cannot be acknowledged, valued or influenced by institutional pressures. By expanding the reach of influence throughout the supply chain there is greater chance of innovative exposure which could be transferred via legitimate practices throughout the supply chain. Risk however is deemed to be a preventative factor for the expansion of wider

reaching values as companies need to be competing with others of a similar size in order to withstand potential failure as expressed in the data:

> *'But you need to be of their size and … capability to take those risks because then, when it does go wrong, they're not going to … they won't suffer from it, you know … in the long term, and then everyone benefits from it, that is true, like as much as people say about them, the whole industry benefits, once they've tested it.' (Mechanical and electrical engineer, supply chain position 3)*

Exchanges occur between organisations of the same size because changes in any business often result in structural change (Caplow, 1957). The high risk construction industry is not generally conducive to innovation, simply because companies need to have a high risk tolerance in order to innovate (Martins and Terblanche, 2003; Steele and Murray, 2004). Therefore incremental changes which are spread via mimetic isomorphic pressures would be considered less of a risk, supporting the notion of collaboration as a way of solving the emissions problem (Panuwatwanich et al., 2008).

5.6.2 Collaboration: Coercive pressures

If mimetic pressures are not strong enough for implementing change for collaborative progress, other pressures may provide greater institutional change drivers. The data showed that collaboration could be enforced via technological methods such as BIM. The BIM process is highly applicable to increased collaboration in the construction industry (Hardin, 2011). As a key component of information management, the government's advocacy of BIM software could act as a coercive pressure enforcing greater collaboration through obligatory technological integration (Coelho and Novaes, 2008; Singh, et al., 2011; HM Government, 2012). Enforcing collaborative processes from the conception of the project via government backed sources could have major benefits for the development of low carbon decision making (Basbagill et al., 2013). There was a distinct acknowledgement of the benefits of collaboration and how it could be achieved in the data. The implicit success factor was the implementation of collaborative processes via the government's insistence on the use of BIM, despite an appreciation of the difficulties which this would present:

> *[BIM] 'I mean the Government wants it to be I think going to a unified model run off of servers where everybody can access this at one time. I think that's a bit of a long way off.' (Architect, supply chain position 3)*

Collaborative construction could be secured as an integral part of the construction industry through coercive pressures for BIM implementation, but only if the government enforces its

use. Although initially expected to become legislatively enforced, the government changed its use to public buildings where appropriate (HM Government, 2012). The coercive drivers for the implementation of new systems could aid the diffusion of low carbon strategy. If companies are forced into taking certain actions then the uptake of innovation would be rapid as regulatory requirements would enforce uptake. Collaborative pressure was considered to be an underlying concept:

> *'No, it doesn't happen enough. There are … it's being encouraged but, again, it's … I think it's just such a lumbering beast that's been going on … that's been doing things the way its been doing them for so long, it's very hard. Recent Government schemes that have tried to encourage collaboration have all been focused on the economy.' (Environmental consultant, supply chain position 3)*

The evidence above highlights the underlying benefits of collaboration in construction which could be highly beneficial for CO_2 analysis. Emphasis has been placed on the economy, as the government's focus on collaborative structures have been put in place for economic advancement which is still considered to take precedence over sustainability issues in construction (Abanda et al., 2013; Hu and He, 2014). Coercive pressures which enforce collaboration on sustainability have proven to be one of the most successful ways to reduce emissions (Interdonto, 2012). As an essential component for the diffusion of innovative products, new concepts could gain momentum through greater communication flow. The diffusion process relies upon personal influences within and outside businesses which can encourage others to adopt strategies (Gatignon and Robertson, 1985). Additionally Rogers' (1971) notion of diffusion providing a form of social change could be readily applied to the transformation in social dynamics required for increased collaboration in construction. In a collaborative system the client would need to be open to influence and other members of the supply chain would be required to surpass social norms of singular achievements and work together overcoming barriers of mistrust. Cohesive action works against the traditional structures of the supply chain system whereby supply chain actors work for their own benefits alone, often driven by greed as discussed in the findings:

> *'Yes, I mean, it's a fantastic idea, yes, and it's the … yes, it's a great idea. On paper it works. It ticks all the right boxes. But I think it's … its problem is that greed is so embedded in the industry that it's hard to get people … you need trust for people to work like that.' (Environmental consultant, supply chain position 3).*

Participants argued that traditional values have been embedded in the construction industry for a significant period of time. Construction companies are primarily driven by cost and

competition; coercive pressures which are secured by traditional supply chain structures and industry values, the product of which has been a reticent industry (Hu and He, 2014). Associated coercive pressures such as supply chain structure, competition and cost appear to have inhibited the sharing of information and the diffusion of innovative strategies. Construction companies have continued to work in fiercely competitive fragmentised compartments where profits are the only consideration to the detriment of innovation (Havenvid, 2015). Innovation must lead to profitability and considerations in innovation are almost always governed by the nature of previous advancement (Brown, 1981). If governmental pressures were placed on the industry to collaborate more, then collaborative measures could be implemented to aid the development of the low carbon decision making process assuming clients were leading the implementation:

> *'Yes. If it's used in the right way and as part of that collaboration platform, yes, that's exactly right, if BIM is used on every project… the Government have got to say well this is the way it is, we have to do it.' (Consultant, supply chain position 3)*

> *[collaboration] 'Is something…we have to start getting a handle on, and that our clients will expect it of us in the future as a number of market leading clients would have incorporated this in to their requirements for certain contracts and bids and tenders.' (Mechanical and electrical engineer, supply chain position 3)*

Coercing and enforcing construction project teams to actively seek collaborative networks for all aspects of the building including carbon emissions data would require client leadership to ensure its successful integration into contracts. Having the ability to collaborate and integrate the supply chain is essential for low carbon decision making (Love, et al., 1999; Cheng, et al., 2001; Love, et al., 2004). If enforced it could encourage greater carbon data sharing enabling the project team to make more informed low carbon choices. Additionally, short term project lifespans add to the difficulties associated with construction collaboration and innovation diffusion - a coercive pressure beyond the industry's control (Dubois and Gadde, 2002).

Short lifespans inhibit long term collaborative plans and ultimately the retainment of organisational memory (Dubois and Gadde, 2002). The prevention of knowledge transfer means that information is lost, a notion implicit in the data findings. Participants discussed each project as conceptual prototypes whereby knowledge was not openly transferred between project parties who endure short relationships (Songip et al., 2013). Collaborative processes do not have the ability to mature which restricts the diffusion of new processes as relationships will not progress beyond single projects. Relationships are critical to the

diffusion of innovation as influence is essential for widespread adoption of products, processes and strategies (Gatgnon and Robertson, 1983). In the current system, it could be argued that due to institutional pressures which hold traditional structures in place the diffusion of innovation is difficult. Long term relationships are scarce, supply chains are fragmented and collaborative influence is lacking which amass to form significant barriers to the diffusion of innovation (Rogers, 1971). Furthermore, the lack of client demand for low carbon innovation is apparent. The power of the client in the chain is critical to the failures of low carbon decision making as the key decision maker and project lead. The role of client power explained through institutional pressures is explored in the following section.

5.7. Client power

5.7.1. Hierarchical supply chains: Client power and influence

The findings highlighted that client power was found to be one of the most significant enablers and barriers to building sustainability as the client takes precedence in the supply chain holding the greatest influence and power (Ahmed and Kangari, 1995; Ryd, 2004). The power of the client was so great that if a particular product was requested supply chain actors would be required to provide it, regardless of sustainability implications as highlighted below:

> *'They were adamant on having slate from China. You look at the embodied carbon on that. Crazy. You know we just get the green guide out and say do you really think you want to get that from there, this is the green guide … no, no, you want that black, looks awful, but that's what they wanted, and they're paying the bill.' (Participant C1)*

The power from the client impacts on the supply chain structure by providing the impetus to follow traditional hierarchical supply chain patterns which are held in place by institutional pressures. The importance of the client has become a normative pressure as it is legitimate practice to meet client requests without question (Ryd, 2004). The client has traditionally been the vital actor in the chain and has continued to fulfil this role. Power imbalances particularly enforced by normative pressures have prevented influential relationships from forming between the client and the rest of the supply chain as each remains set on their own responsibilities (Cheng et al., 2001; Kornelius and Wamelink, 1998). Emphasis on cost, quality, time and traditional construction procurement systems has inhibited the development of innovation in the industry as premiums are placed on normative structures and terms. The singularity of supply chain roles has encouraged a self-protecting supply chain sceptical of influence. The prospect of knowledge sharing appears to open up potential for risk as

companies conceal ideas which may increase profits. Movement away from social norms through fears of contract loss and failure in a highly competitive industry is simply avoided (Kumaraswamy and Dulaimi, 2001).

It is argued that higher levels of innovation often occur when innovative procurement methods are used which is usually the product of a much more integrated team, furthering the importance of communicative processes in the diffusion of innovation (Walker at al., 2003; Rogers, 1971). It is often acknowledged however that businesses will always try to resist change due to social and cultural barriers which are often developed over time due to normative pressures (Peansupap and Walker, 2005; Abbott, 1988). The positive changes to potential procurement practices through integrated approaches further supports the argument for a network based supply chain to aid the diffusion process. The suggestion is that integrating procurement methods could enable low carbon decision making strategies to diffuse throughout the supply chain (Kumaraswamy and Dulaimi, 2001). Current procurement practices discourage innovative practices (Blayse and Manley, 2004). Supply chain actors are thought to adhere to structured roles in order to protect themselves from failure and contract loss, something which innovative processes may not support (Kumaraswamy and Dulaimi, 2001).

The structure of construction projects has meant that knowledge is often not transferred to further projects, particularly if the client does not require it (Blayse and Manley 2004). Construction clients' requests differ for each project, restraining the potential for knowledge transfer (Dubois and Gadde, 2002). Some clients can be highly innovative, whilst others may not be particularly open to innovation, ensuring the use of tried and tested building techniques and avoiding risks (Blayse and Manley, 2004). The key to diffusing low carbon innovation is reaching those who are not naturally innovative. Client outlooks on issues such as sustainability can be culturally driven.

Variances in culture types affect the client's environmental attitudes which may be influenced internally or externally (Jones et al., 2007). Cultural differences will impact on the trade-offs which occur between supply chain actors which are highly dependent on ethical foundation (Jones et al., 2007). The power of cultural forces within an industry means that currently environmental issues are low on the agenda. Cultural influences between the client and the supply chain are opportunistic. These influences could have the greatest impact on the diffusion of low carbon decision making strategies. As new relationship formations occur

there are greater prospects for increasing collaborative processes and shared learning opportunities (Rogers, 1971; Peansupap and Walker, 2005).

The emphasis on the client is supported by von Hippel (1976) who emphasised the position of the 'user' or 'client' in innovative processes. His paper noted that in around eighty percent of cases the user is the key innovator. Von Hippel's argument correlates with Rogers (1971) innovation curve showing innovators as the smallest group in the diffusion process (see Figure 2.10). The linkages between Roger's 'S' curve and the supply chain are clear as in the construction supply chain the smallest group (clients) have the greatest power to innovate (Kilinc, Bazak and Yitmen, 2015).

Currently, Institutional pressures force clients to behave in certain ways, i.e. financial restraints and contractual obligations act as a coercive pressures maintaining traditional structures and hierarchies. Additionally, the normative pressures which expect clients to remain at the helm of the project are positive for construction clients, therefore there is little motivation to relinquish power. Having the client at the top of the chain driving innovation is the social norm (Briscoe and Dainty, 2005). The importance of client influence, innovation and the power the client held was considered to be one of the most important aspects in the development of low carbon decision making.

Client power itself could be seen as a coercive pressure by the rest of the chain who are often bound by client demands; however, the normative pressure of social expectations and norms within the industry have provided the cornerstone by which client power has been held in place. The expectation of client leadership meant that other supply chain actors did not try to influence sustainability outcomes. Interestingly the client is often forced into certain actions by external coercive barriers such as cost, which inhibit the development of low carbon innovation (Prue and Devine, 2012).

The findings showed that there appears to be a circularity of circumstances which inhibit sustainability originating from client power. The client is bound by contractual coercive pressures. Clients also accept normative pressures as they are favourable to them as they are held in high esteem. It is not therefore wholly feasible or desirable for the client to advocate change. If the client does not lead the implementation of low carbon innovation then diffusion is highly unlikely to occur. The hierarchical nature of construction supply chains means that innovations must be led by the client (Ryd, 2004; Cao, Li and Wang, 2014; Stock

et al., 2000; Rosinski et al., 2014; Dirix et al., 2013) which is supported in the following evidence:

> *'Hmm … that's a difficult one that is. I think … well, the client's got to ultimately lead it, and has got to want it, and I think if they lead it and want it, it'll get in to everybody's head that it's going to happen. Whether it's the architects that sort of … takes the lead or the services consultant, I'm not sure.' (Architect, supply chain position 3)*

Although the client may be led by coercive pressures, normative pressures allow the client to remain the key actor in the construction supply chain. There is a perception that all innovative change requires client leadership in order for it to diffuse (Ryd, 2004; Cao, Li and Wang, 2014). If client demand for sustainability is limited, other supply chain actors will see limited advantage to implementing low carbon construction strategy. Additionally, other supply chain actors working in close proximity with the client such as architects felt that they were not in a position influence sustainability outcomes if it was not prompted by the client. An example of this can be seen below:

> *'It can't really have an effect because people aren't engaged early enough and is there no appetite for it. Well, again, I see it, from experience, and this is just my working experiences, there is no appetite to measure the building energy through its whole lifecycle unless it's prompted.' (Architect, supply chain position 3)*

Institutional pressures exerted upon each section of the supply chain have worked against those who wish to implement sustainability into construction practices. Fear of transcending social norms and losing legitimacy has discouraged the implementation and diffusion of low carbon practices. If the implementation of new practices requires client backing and approval and this is not available then low carbon practice will not diffuse. The data shown above suggests that there was simply no call for emissions measurement unless prompted and directly influenced by the client. Often the client will choose to forgo any further costs or additional practices to ensure emphasis is kept on remaining in budget, creating high quality buildings and finishing on time (Abanda et al., 2013).

5.7.2 Influencing the client

The client's position has led other actors in the supply chain to address whether they *should* be exerting greater influence over the client in low carbon construction. There was a suggestion that there was an overreliance on following social norms. The quotation below highlights how normative influences exerted on the supply chain inhibit client influence regarding low carbon decision making:

> *'Unless in a way, as part of an architect's obligations, once you're' in a relationship with a client, you do have an obligation to inform them of a lot of things, whereas I don't think you have to do anything to do inform them about how environmental they would have to be, you know, because you do have to be safe, you do have to be … there's other factors that are included.' (Architect, supply chain position 3)*

The design team acknowledge that there is a clear obligation to inform the client on many aspects of the project but there is no obligation to advise them on environmental issues. Normative pressures which informally encourage information exchange between the design team and the client does not enforce the inclusion of sustainability outcomes. Therefore firms will not view increasing environmental programmes as a legitimate practice (Zhu and Sarkis, 2007). One solution which seems to have aided the development of influence between supply chain actors and the client is the building of relationships as illustrated by the evidence below:

> *'You know develop a relationship with the client, so that they continue to make sure that the building functions as it should do, I think that can certainly help sustainability, and I think that's what a lot of good practices do who are committed. They develop bonds and relationships with the client and manage multiple buildings and, in that way, they continue to come back and check and refine and resolve issues, you know, every building is a new thing and there are always going to be minor little things that go wrong, sometimes they're major, umm, because you're testing something in an unknown environment.' (Architect, supply chain position 3)*

Although relationships are occurring it is not yet considered a social norm and so therefore is not a normative institutional pressure. In order for relationships to become established, the act of increasing influential relationships would need to become the norm, exerted through institutional pressures.

5.7.3 Influential relationships between the client and the supply chain

The establishment of the importance of client power has indicated that in order for changes to occur throughout the supply chain the client must be influenced to make more informed low carbon choices through the perception of success (von Medling et al., 2013). Influencing the client is at present difficult due to the hierarchical nature of top down supply chain approaches (Rosinski et al., 2014; Dirix et al., 2013). By addressing the position of the client and presenting the possibility of supply chain reorganisation, the potential to influence client decisions becomes greater.

Influential relationships are a key component of diffusion literature and central to innovation (Dubois and Gadde, 2002; Miozzo and Dewick). Relationships with the client are essential to

ensure that innovation diffuses via information flow pathways within the supply chain. With increased levels of integration, innovation has potential to reach those whom it may not have reached under previous circumstances, furthering the perceived potential for networked supply chain approaches (Dubois and Gadde, 2002; Cheng et al, 2001). It is thought that a supply chain network could aid the retention of knowledge and relationships as members of the supply chain work in close proximity rather than working in fragmented silos (Songip et al. 2013; Blayse and Manley, 2004). A change such as this would require movement away from institutionalised norms.

The pressures of client influence were found to be predominantly normative however there is some evidence of coercive pressure. For example, supply chain actors are obliged to inform the client on price due to contractual agreements (Coercive); however they are not obliged to inform them on environmental outcomes. There was an indication that once the expected specifications are met, then the parties involved do not go beyond this and it is not encouraged (normative). Reasoning behind this could be due to a lack of influence exerted on each supply chain actor down the chain:

> *'Unless in a way, as part of an architect's obligations, once you're' in a relationship with a client, you do have an obligation to inform them of a lot of things, whereas I don't think you have to do anything to do inform them about how environmental they would have to be.' (Architect, supply chain position 3)*

> *'But in answer to your question I don't think the client is probably very well informed because, yes, who would be the person to inform them really. Would it be architects once they've ... once you're at RIBA work stage 1 kind of thing.' (Architect, supply chain position 3)*

The findings showed that client influence greatly impacts on client innovation. Research participants acknowledged the importance of the supply chain and the impact that supply chain positions have on the ability to innovate - *'It [innovation] depends on where you are in the chain'.* The importance of influencing the client to encourage innovation is the key factor in establishing environmental innovations in construction projects. Often those below the client in the supply chain will not inform them about low carbon options as they are coercively and normatively driven to adhere to the client's needs. The client is driven by his or her own coercive pressures such as contractual and financial obligation (Yang and Chen, 2015). Any additional considerations outside of the project scope are often neglected.

The structure of the supply chain inhibits the ability of those in other positions to innovate leaving the onus on the client. Clients are not required to agree on any innovation which may

potentially be used i.e. behavioural processes, technology and any education and or training which may be required to use the innovation in order to ensure its use (Ryd, 2014; Janda, 2011). The notion is that if the client takes on innovation then the rest of the chain will follow, but often only for that specific project. It is due to the hierarchical nature and linear structure of the supply chain that the construction industry has been considered as a relatively low innovation industry, even though as suggested in the data *'Innovation doesn't have to be the grand new…just something which is different'* (Songip et al., 2013). Unfortunately the implementation of any innovative process is considered risky. Coercive pressures placed on the client by regulation, legislation, cost and risk are inhibiting the development of low carbon innovation.

A possible solution to the concerns surrounding risky ventures could be to introduce change through incremental steps. Not only does it reduce risk but enables those involved to adapt to new pressures slowly (Male and Stocks, 1991; Slaughter, 2000), linking to the prospects of steady behavioural modification. The findings suggested that behaviour modification was essential for implementing low carbon solutions but the means to change behaviour was also essential:

> *'I mean you can modify your behaviour… there's no point in saying, right, recycle everything, and not put any bins out. If you put five bins out with five different classifications then tell them to recycle at least they can start to do it, so you've got the behavioural aspect and also you've got this technology or whatever. You're giving them the means to do it.' (Subcontractor, supply chain position 4)*

The implementation of small behavioural changes could aid the development of sustainability. Small manageable changes have shown to be much more effective than radical changes. Some have argued that incremental innovative changes are the only innovation relevant in the construction industry due to high risks (Male and Stocks, 1991). Behavioural change is important to the development of sustainability as it enables sustainable attitudes to filter down the supply chain, but more importantly these changes must be influenced by the client, whose power is crucial in low carbon development.

The most prevalent institutional pressure found in the data was the extensive client power exerted over the entire supply chain (Ryd, 2014; Kilinc, Ozturk and Yitmet, 2015). Client power appears to result in the disruption of relationships between supply chain actors. Clients may decide to engage in relationships with architects and suppliers who solely focus on cost and do not try and influence low carbon decisions (Ahmed and Kangari, 1995). Power can

ultimately reduce the ability of the rest of the chain to extend their expertise in sustainability as they aim to provide client requirements as suggested in the findings:

> *'No one talks about lifecycle costing or … much, mostly because I think we do … the vast proportion of our schemes are design and build contracts which means that the … your client, during those stages, is the contractor, who doesn't care about anything but the capital costs of the building.' (Architect, supply chain position 3)*
>
> *'It's whether or not there's a client or someone who is willing to pay for it or wants to tag that on as something in their building.' (Architect, supply chain position 3)*
>
> *'They choose not to because they don't have to, and therefore it's a cost saving.'(Architect, supply chain position 3)*
>
> *Yes, whoever's paying for it, is the person that needs to say that that's important, yes.' (Architect, supply chain position 3)*

Focus remains on capital cost to the detriment of sustainable outcomes because there is no demand for low carbon buildings which must come from the client. Capital cost savings are the prime objective, but perhaps short-sighted when the long term benefits of low carbon buildings are realised. Immediate low cost will almost always be chosen over long term low cost in the form of low carbon initiatives (Feminias, Kadefors and Eden, 2009). The data showed that low carbon building development will only occur if is specifically in the contract, if not the bare minimum will be carried out:

> *'Unless it's something they have to do, because it's written in to the contract, it's not going to be a concern of theirs really. It tends to be a tick box exercise.' (Architect, supply chain position 3)*

Client demand for low carbon construction is the only requirement for a sustainable building (Ryd, 2014). There was an emphasis on the supply chain placing responsibility for sustainability and low carbon strategy on the client. Others felt powerless to have any sway in low carbon decision making. Participants suggested that '*it's really down to the clients deciding it's important enough to build in to the requirements'*. The client decides on particular specifications and the supply chain follows in order to win and maintain contracts (Ahmed and Kangari, 1995). Evidence suggests that the structure of the hierarchical supply chain has hindered the development of innovation in the construction industry maintaining its low innovation reputation (Songip, et al., 2013).

In the event that a client may require an emissions analysis from the conception of the project the contractor may find difficulties in obtaining the information from the supply chain. The root cause of emissions would need to be traced when accounting for all CO_2. The problem

arises when the data is simply unavailable; hence the technological focus on emissions analysis (Chrisna et al., 2011). The need for carbon traceability could provide an indication of where coercive pressures from the client could aid the development of sustainability. Increased collaborative processes could ease data dissemination and enable those involved in a project to make more informed low carbon decisions (Orlander, 2007: Ayuso et al., 2011; Bal et al., 2013; Hernandez and Kenny, 2011). The ease of obtaining this data is currently difficult as there is low demand and a reliance on cost, quality and time. The exclusion of carbon impacts is still considered to be standard practice (Yang and Chen, 2015). There was a definite sense that the focus on traditional values eliminates the risk of increasing costs and running over time:

> *'People are looking at cost, risk, compliance, profitability, stuff like that. I think, at the moment with carbon, it's just … it's still so low down the pecking order and things are not really considered as much as what it should be, but I think that will change over the next five to 10 years. I think it will have to become more important because of the Climate Change Act.' (Consultant, supply chain position3)*

There was an acknowledgement that coercive influences such as the Climate Change Act could have a significant impact on carbon emissions, but the prospects were long term. Additionally, the Climate Change Act itself provides no specific construction legislation regarding emissions outputs (Department for Energy and Climate Change, 2008). In the near future the focus was not expected to change beyond traditional values. With clients currently being driven primarily by cost, those throughout the supply chain are influenced by cost. If the client requests low carbon strategies or products, only then will the rest of the supply chain follow suit as demand increases (Ryd, 2004). The evidence below provides acknowledgement that there are currently two types of clients, those who strive for low costs and those who strive for sustainability. Both types of client are ultimately driven by a series of coercive pressures from funding bodies and legislation. There was a sense of the need for increased legislation to increase the demand for low carbon buildings:

> *'On the lower end of the spectrum clients are normally just driven by money rather than sustainability, unless there is a reason for it to be sustainable, and that's where I go back to the sort of the PR side of things.' (Architect, supply chain position 3)*

> *'Certainly clients are becoming more involved as more pressure is put on them. There's still a bit more legislation to go I think before it will become mainstream' (Architect, supply chain position 3)*

The clients interviewed in the data collection process also acknowledged these pressures. For example investments and pay-back time for low carbon technologies was a key factor in the development of their sustainability programmes:

> *'Well I think … I don't want us to do things from a sustainability point of view or energy savings point of view, just for the sake of doing it, so for example, we looked at wind, could we do something with wind, but I mean, the investment which is a barrier, it's the amount of investment and the pay back, you look at putting wind turbine on, it was something like 12 years pay back, so we ruled that out.' (Client, supply chain position 6)*

The client is not always free to act sustainably if the costs do not allow it. Clients from different construction sectors are subject to a series of legislation such as the Social Value Act, an indication that some are addressing sustainability using the triple bottom line and remaining competitive (Hart, 1995; Rodriguez-Melo and Mansouri, 2011; Florez et al., 2013).

> *'So yes, clients I think are absolutely pivotal to this and that doesn't have to be a retail … a physical retailer with physical customers, I think in some of our bigger engineering construction contracts, industrial and infrastructure, clients have very strict requirements too, and things like the Social Value Act.' (Mechanical and electrical engineer, supply chain position 3)*

Coercive pressures placed on the client have been found to both aid and hinder the development of low carbon buildings. Client pressures such as capital cost appears to have hindered low carbon decision making as any additional costs on procedures which are not enforced is ultimately considered as 'additional' work whereby errors can increase supply chain risks (Love, et al., 1999; Cheng, et al., 2001; Love, et al., 2004). Coercive legislation however has in some respects aided the development of low carbon buildings, particularly in subdivisions within construction and the public sector which have in some cases had to respond to legislation. The core problem with the coercive pressures imposed on the client is that they are inhibiting collaborative networks as the client is at the head of the supply chain (Ryd, 2014). Collaboration can be used to solve problems in the construction industry via the dissemination of information, opening up the possibilities of innovation diffusion, decreased business risk and easing low carbon choices through these means (Rogers, 1971; Cheng et al., 2011). In cases where clients were actively seeking sustainable buildings interest was diffusing to other professionals, but primarily among those who had the same positive attitude towards sustainability as indicated in the findings:

> *'It's the clients who are pushing the agenda and leading professionals who have those same attitudes.'* (Architect, supply chain position 3)

The transfer of information via homophilous influences indicates the need for greater influence between all supply chain actors (Gatignon and Robertson, 1985). The diffusion of low carbon innovation throughout the supply chain can only be achieved by reaching those who are not accommodating the same set of sustainability principles (Gatignon and Robertson, 1985). Heterophilous influences are critical for the diffusion of low carbon innovation. By reaching and appealing to those who would not normally adhere to low carbon strategies via weak ties, low carbon strategy can be diffused further (Granovetter, 1973). Weak ties between groups ultimately have the potential to explore previously unobtainable avenues of business and innovation diffusion, whilst simultaneously encouraging new ideas by transcending normative barriers (Gatignon and Robertson, 1985). Weak ties are highly important in the adoption and diffusion of low carbon innovation as the greater the number of people which an innovation can reach, the faster the 'critical mass' of adoption is reached and so therefore the sooner the innovation spreads throughout an industry or supply chain (Rogers, 1971).

5.8 Risk

Risk is considered to be primarily coercive and mimetic; however the data highlighted that it also shows some evidence of normative pressure. The current social norms of the industry discourage risk taking. The very nature of construction is high risk and high cost and so traditional building methods are considered to be the accepted standard (Blayse and Manley, 2004; Hampson and Tatum, 1997). It could be argued that new developments such as low carbon technologies and processes are not taken up in many instances due to the perceived risk; therefore firms would rather stay within socially accepted restrictions (Blayse and Manley, 2004). An example of this was discovered when a participant outlined that if a new technology or process is '*unfamiliar and you're not sure it's going to work … people will be hesitant'.* The risk of implementing new processes when outcomes of success are uncertain is a normative pressure. It inhibits the development and diffusion of innovation due to the perceived risk of stepping outside of what is considered safe, legitimate and correct.

Furthermore, there was an indication that as people increase the use of a particular product then the risk is reduced. If a product was seen as *'readily available'* then the participants considered that more people were likely to try it. Availability can be applied to the diffusion of innovation curve put forward by Rogers (1971). If a product is available and enough people take on a product or strategy then a 'critical mass' is reached. Once these three factors

occur diffusion will ensue more easily, the success of this will depend on the communicative relationships between individuals in a social network (Gouws and Reed van Oudtshoorn, 2011; Littlejohn and Foss, 2008). The adoption of a strategy is dependent on the perception of success something which has not been heavily noted in relation to environmental applications in construction (Heany, 1983). Personal influence is critical to the rate of uptake even if the strategy or product is readily available (Bass, 2004).

If greater numbers of people take on a product then ultimately it becomes more legitimate to use it and so therefore a future social norm. The endeavour for legitimacy illustrates a cross-over of institutional pressure and the theory of diffusion. Mimetic pressures would need to felt before normative pressures were able to transform a new concept into a social norm as an accepted part of construction projects (Gatignon and Robertson, 1985). The use of diffusion theory is able to explain how mimetic pressure can be used to adopt an innovation which then can be transferred into a social norm. As an innovation is implemented to the point of a critical mass, others feel that they may get left behind and so therefore adopt unfamiliar strategies to remain legitimate.

Conversely if a new development remains unfamiliar then it is less likely to become a normative pressure. The research argues that a collaborative supply chain framework could aid the development of familiarity of new low carbon products and work processes, ultimately encouraging low carbon innovation to diffuse (Jervis et al., 2016). In a collaborative system, data, knowledge, processes and risk could be shared. If collaboration and relationships develop, the supply chain would be more likely to take on innovation as the perceived risk would be reduced (Rogers, 1971). The importance of personal relationships in this instance is manifest as highlighted by the following quotation:

> *'There's so many aspects to something. It often is down to personal relationships as well, there's an existing personal relationship and so we'll stick with these people, or it's they've heard that this company is difficult, or this bit of technology doesn't work and they don't want to risk.' (Architect, supply chain position 3)*

Risk inhibits innovation as the client does not like to be the *'guinea pig'* and the management and design team will struggle to influence the client; perhaps due to the hierarchical structure of the supply chain and associated problems (Kilinc, Ozturkb and Yitmen, 2015). Additionally, *'people hate change'* and so therefore traditional structures become ingrained in institutions. The data highlighted that once tested and if an innovation is successful *'the whole industry benefits'.* The expansion of collective benefit further supports the view of a

collaborative network supply chain system which would enable successful low carbon products and strategies to diffuse rapidly with reduced risk via knowledge sharing systems. Increased awareness of strategies eliminates surprise and enables acknowledgement of success. Evidence of this suggestion has been found in Toole (1998). Toole argued that those who are more willing to take on new innovations are those firms who take measures to significantly reduce the risk. Acquiring large amounts of information on a new product or strategy is a tool used to decrease perceived risk.

Increasing information on a particular product or strategy through collaborative networks enables incremental change to occur. More people view the benefits and adopt small changes which often have cumulative effects (Slaughter, 2000). Normative pressures which hold traditional structural systems in place indicate that the construction industry is uneasy about working outside of traditional boundaries due to perceived business risk. As a traditional industry, construction companies are not comfortable with adopting new products and systems which force them to work outside of their traditional activities or increase business risk (Chevalier and Le Téno, 1996; Dimoudi and Tompa, 2008; Blengini, 2009; Blengini and Di Carlo, 2010; Slaughter, 2000 and Toole, 1998).

In addition, low cost, simple and low risk analysis systems which are easily integrated are notoriously inaccurate and based on vast amounts of assumptions which are often untraceable. The problem of inaccuracies and untraceable data was supported by a significant proportion of LCA literature (Scheuer et al. 2003; Verbeeck and Hens, 2010; Williams et al. 2012; Wang and Shen, 2013). Challenges associated with common methods and tools are an issue, however these issues could be reduced through enhanced collaboration. If all supply chain actors are using the same methods of calculation (something which could be agreed via collaborative approaches) then products and processes become comparable.

Communication also encourages awareness of the importance of calculation and low carbon decisions. Once this awareness and uniformity of data has occurred and a strategy or process is in place, it is important to understand how new innovations become common practice and a socially accepted norm within an industry. Moreover, incremental innovation secured by collaborative processes could lower risks and increase the use of innovative low carbon decision making strategies (Dimoudi and Tompa, 2008; Blengini and Di Carlo, 2010). A collaborative system could increase risk tolerance which is essential for taking on new innovations (Martins and Terblanche, 2003; Steele and Murray, 2004).

Innovative processes would be widely received and used if the sense of risk for the client was reduced. Risk is often reduced by small incremental steps which are taken on slowly between supply chain actors who potentially share the risk (Slaughter, 2000). The importance of supply chain relationships in aiding the development of low carbon decision making has provided an argument for the creation of a network supply chain which could theoretically increase communication. The influence of supply chain actors could ease the dissemination of low carbon data, thus enabling the client to be influenced into making low carbon decisions whilst simultaneously being informed (Rogers, 1971). A network supply chain framework is a positive example of how such a system could be implemented (Cheng et al., 2001). In the current supply chain system which feeds the client's power participants agreed that:

> *'It's…down to the clients deciding it's important enough to build in to the requirements.' (Architect, supply chain position 3)*

One of the core reasons for the occurrence of mimetic isomorphic pressure is risk potential. Mimicking others is thought to eliminate risks by acknowledging success and eradicating the need to outlay costs on an innovation which may fail. Businesses that are seen to be successful will be imitated (DiMaggio and Powell, 1983). In industries which experience high risk contracts frequent uncertainty encourages them to move towards mimetic isomorphism and it is accepted with much more confidence than forging ahead with brand new and unknown innovation (Deephouse, 1996). Imitation is acknowledged as a legitimate solution to uncertainty (Massini, Lewin and Greve, 2005). With low demand, and high levels of data collection technology in a saturated market, implementing unknown low carbon strategies with high cost is seen as a high risk (Toole, 1998); a strong theme running throughout the findings:

> *'Innovation is risky and that's why you wait for someone else to take the risk often, unless you are one of those innovators, and then when it looks like it's okay, then other people take it up, so …' (Architect, supply chain position, 3)*

> *'I mean if there's a way of … there is no way of reducing the risk with innovative stuff, other than to do it, and test it and see what happens I guess.' (Architect, supply chain position 3)*

Innovative processes must lead to profitability and this is mostly determined by past success (Songip, et al., 2013). Much of the existing technology for CO_2 calculation has suffered from poor uptake rates or is simply not required once purchased. The similarity of products had

provided potential reasoning behind these poor uptake rates (Gatignon and Robertson, 1985). LCA failures have encouraged movement away from carbon measurement. Breaking this cycle could prove difficult without the use of increased communication channels between those outside of normative business networks (Gatignon and Robertson, 1985). Often it is those who remain within their business group which do not innovate as the findings suggest:

> *'It often is down to personal relationships as well, there's an existing personal relationship and so we'll stick with these people, or it's they've heard that this company is difficult, or this bit of technology doesn't work and they don't want to risk.' (Architect, supply chain position 3)*

Without exposure to companies who may be overtly innovative in CO_2 emissions analysis, success cannot be acknowledged, valued or taken up via mimetic pressures. By expanding collaborative networks there is an increased chance of innovative exposure which could be transferred via legitimate practices throughout the supply chain. Risk tolerance however is deemed to be a preventative factor for the expansion of wider reaching values as companies need to be competing with others of a similar size in order to withstand potential failure:

> *'But you need to be of their size and … capability to take those risks because then, when it does go wrong, they're not going to … they won't suffer from it, you know … in the long term, and then everyone benefits from it, that is true, like as much as people say about them, the whole industry benefits, once they've tested it.' (Architect, supply chain position 3)*

The high risk construction industry is not encouraging of innovation as companies need to have a high risk tolerance in order to innovate (Martins and Terblanche, 2003; Steele and Murray, 2004). Therefore incremental changes which are spread via mimetic isomorphic pressures would be considered less of a risk supporting the notion of enhanced collaboration as a way of solving the emissions problem (Panuwatwanich et al., 2008).

5.9 Cost

In any business cost will be an important factor and the construction industry is no exception. The three core elements of any construction project have traditionally focused on cost, quality and time (Abanda et al., 2013; Monghasemi et al., 2015). Cost was highly relevant when discussing the implementation of sustainable practices in the construction industry and highlighted the importance of the client who holds most power regarding project costs. Cost is primarily considered to be a coercive pressure as often the client is led by the budget. Over-running budgets can have significantly detrimental impacts on profit (Yang and Chen, 2015).

The evidence from the data has suggested that it has in some respects become a normative pressure as the onus is expected to be on price and cost alone. Disregard of future long term running cost benefits which may be found from using sustainable construction methods is a standard practice (Wang, Chang and Nunn, 2010). The impetus for technological developments has been on cost, as discovered with the implementation of BIM which has been implemented primarily for efficiency and cost reduction (Bynum, et al., 2012). Emphasis on the upfront construction costs is considered to be the social norm:

> *'When they're trying to get hold of something it's always to do with how much it costs.' (Architect, supply chain position 3)*

The evidence indicated that the pressure throughout the supply chain was based on cost and no other information is generally required, particularly regarding CO_2 emissions. The data above implies that the expectations for construction are developed around cost and not sustainability and emissions outputs (Abanda et al., 2013: Monghasemi et al., 2015). It was even suggested that when a technology or system is put in place which is for *'the benefit of the environment'* cost is still often the key driver. Interestingly relationships which have occurred within the industry have bred a perception that '*anything environmental costs more'*. The perception appears to be entrenched in the industry and is stopping construction members from moving outside of the primary consideration of capital cost (Feminias, Kadefors and Eden, 2009).

It was also acknowledged that this focus could be down to how well informed and educated the construction supply chain are regarding sustainability (Janda 2011; Akintoye et al., 2000). The suggestion was that if people were more informed about the long term benefits and potential outcomes of the implementation of sustainable buildings, then they may be able to understand the cost benefits. Additionally, often in situations with complex outcomes, clients would be faced with large volumes of uncertain information, making the decision making process highly challenging (Hambrick and Mason, 1984; Dutton and Jackson, 1987).

The importance of communication and collaborative throughout the supply chain is imperative as only through information sharing will environmental benefits be fully understood. As environmental benefits gain momentum, pressures for the implementation of sustainable buildings will become normative as social norms develop. Emphasis was placed on the client and the importance of influencing the client to demand low carbon buildings and not just focus on cost,

'If the consumer can be encouraged to demand more sustainable buildings, then they will make them.' (Consultant, supply chain position 3)

The acknowledgement of client power in relation to cost was exceptionally important for the development of the supply chain framework (see Figure 5.2) as it enabled the realisation that influence was absolutely critical in the development of low carbon buildings. The findings highlighted that the two greatest barriers were *'cost and how well informed people are'* both of which provide evidence of normative pressures which have developed over time to conform to social norms, trade recommendations and traditional and retained power structures. Education and influential relationships form a key part of knowledge acquisition which in most cases was thought to be lacking in environmental decision making (Janda, 2011; Dubois and Gadde, 2002). All of these factors provide further evidence that stepping away from social norms is considered to be risky which is not conducive to high risk industries such as construction (Hampson and Tatum, 1997).

There was a perception that green innovations and low carbon products typically cost more than their high carbon counterparts (Kats, 2003). Cost was perceived to be a defining factor for the client's vision on sustainability as ultimately they had the greatest decision making (Ahmed and Kangari, 1995). As discussed, there was an indication that clients' fall into two categories; either they are focused on sustainability or cost:

'It *depends what the drivers are…whether it be cost or sustainability.'(Participant A1)*

'There's a perception that green costs more.'(Participant E1)

The quotations above implied that any solution to the problem would have to enable both aspects to be dealt with simultaneously. In the literature, cost underlies many aspects of all construction practices including the implementation of software, technology and BIM. The implementation of BIM was initially proposed to improve the efficiency of the building process and so therefore directly reduce costs incurred through waste (Bynum et al., 2012). It was implicit in the findings that the root of the emphasis on cost was due to the client's control over the project, correlating with the client's powerful role in all building projects (Ryd, 2004). Projects where the client had been influenced to make a sustainable choice was generally only in cases where there was a large cost saving;

'We saved about 20% of the cost. So it influenced the client to always want to be green and do the right thing.' (Participant D1)

The acknowledgement above highlights cost as a powerful coercive pressure which is enforced on clients and pressures them to behave in certain ways. Such pressures are forced upon clients by higher external bodies often preventing them from innovating as they simply do not have the funds or the risk tolerance to do so (Martins and Terblanche, 2003; Steele and Murray, 2004). Innovation was considered to be expensive and ultimately needs to be competitive as shown below:

> *'One of the things I think you said was because it's quite innovative, some of this, it can be quite expensive and I think that's a clear barrier isn't it really. It's a commercial world. We're here to make money. If it's commercially viable we will start using it. If it's above and beyond what you'd normally pay to build a property, for instance, you're not going to choose that, so it needs to be competitive.' (Main contractor, supply chain position 5)*

The clients interviewed suggested they are governed by costs. Other sections of the supply chain such as management and design provide low cost options as they are forced to do so, even if they perhaps have a greater sustainability ethos than the client as the following quotations illustrate:

> *I can see why you're arguing for that, it's really nice that you care, but it costs too much, usually, is the end result, it's too difficult, costs too much, takes too long, too complicated.' (Architect, supply chain position 3)*

> *'Yes, I think, because it's so money driven, I think focusing on the consumer and I do think that, yes, developers do see that as valuable, so if the consumer can be encouraged to demand more sustainable buildings, then they will make them.' (Environmental consultant, supply chain position 3)*

As the data shows, even if the client is in favour of using low carbon products and processes, they are governed by cost (Wigglesworth, 2012; Yang and Chen, 2015). Cost is illustrative of the coercive pressure placed on clients which are directly relating to unsustainable outcomes. These pressures appear to limit the development of low carbon decision making processes. The solution to engaging clients in sustainability activities appears to lie in the potential to influence clients. As the quotation above suggests, the focus on the customer (client) alone has developed a barrier to innovative thinking. The heavy reliance on cost has resonated down the supply chain. In order to remain competitive others must follow suit and provide the lowest cost option in the highly competitive industry as indicated below (Sarrina Li and Lee, 2010).

> *'I know it sounds a bit ruthless but we obviously work to a price really and we'll do as much as we can. We'll do whatever we can to meet that specification. We'd love to spend time looking at the carbon analysis of buildings probably a bit more, but*

because it's a competitive industry, we've got to keep our design costs down to a minimum.' (Mechanical and electrical engineer, supply chain position 3)

As decisions in the construction industry are generally made around cost, any changes made regarding sustainability will need to be aware of this concept. Therefore, theoretically, implementing low cost carbon analysis procedures would have more success. There was a sense that particularly management and design teams would like to implement low carbon buildings more frequently but the demand for it was simply not there from the clients. Therefore there is an argument for greater influence and collaboration between supply chain parties which is currently restricted via coercive cost pressures. The ability to trace carbon through collaborative networks could provide a low cost solution to low carbon decision making based on collaborative data sharing systems and not solely on technological solutions (Scheuer et al., 2003; Verbeeck and Hens, 2010; Wang and Shen, 2013).

Additionally the economic climate was also highlighted as a key barrier to the development of low carbon construction as the following quotation suggests:

'In 2007 the demand and the interest in sustainable construction was, I think, at a high, but it was very very high on people's agendas. Then 2008 came, credit crunch, construction industry basically demand for new buildings, in particular, types of buildings that we're involved in, industrial, logistics buildings, that type of thing, it fell off a cliff.' (Subcontractor, supply chain position 4)

Pre-recession in the UK, sustainability was at the forefront of construction as clients had increasing amounts of money to spend on sustainable buildings; they could afford to wait for pay back. With the economic downturn, clients found themselves with less money and so therefore capital cost reverted back to being the most important element of construction to the detriment of sustainability (Tansey, Spillane and Meng, 2014).

5.10 Technology

Technological solutions to carbon emissions had a strong presence in the data. It can be argued that the pressures exerted on the supply chain by technological solutions are predominantly normative. Historically the construction industry has dealt with sustainability via technological processes (Abanda et al, 2013). Studies such as Crawford and Treloar (2005) and Dixit et al. (2013) for instance have excluded human decision making processes in favour of the more highly developed technological and mathematical approach. The application of technological solutions has become the norm for emissions analysis evidenced by the sheer volume of calculation products (Ding, 2008). The literature suggested that many

consider technology as the expected standard in the industry, evidenced by the governmental technology focus with the application of BIM (HM Government, 2012). The appetite for scientific solutions has led to a market saturation of LCA products and increasing emissions (Strategic Forum for Construction, 2010).

The research findings were heavily supportive of technological solutions, specifically BIM, which was expected to continue throughout the research. As the research progressed, BIM was much less significant than the literature suggested - supported by the depletion of frequency in the findings. This was in line with the latest NBS report which has shown a decrease in BIM uptake despite increased overall awareness, perhaps indicating a movement away from the technological approach (NBS, 2014). Additionally, it was highly representative of the sense of environmental inertia currently experienced in the industry.

The development of BIM is subject to normative pressures from industry associations (Cao, Li and Wang, 2013). The developers of BIM (AutoDesk) previously developed the CAD drawing system and have significant sway within the industry. BIM is the only design tool that could be used for environmental application which has gained significant government backing (AutoDesk, 2013; HM Government, 2012). The key to success however is encouraging the industry to take on new technologies and for them to become the social norm, reaching widespread adoption through diffusion. In essence such a large company as Autodesk may be considered legitimate due to their previously successful applications (Bhakoo and Choi, 2014). The implementation of the CAD drawing system was an example of how innovation can diffuse throughout the construction industry. From hand drawings, the system revolutionised the construction industry architecturally (Kale and Arditi, 2010). The sway behind the company producing BIM may therefore have some influence in its widespread adoption.

The findings suggested that people were conforming to BIM implementation slowly. There was a sense of expected apathy towards the technology, and a perceived sense of expectation of BIM awareness. There was also an emphasis on the consciousness of being seen to be using BIM or at least thinking about it, as illustrated by the following quotations:

> *'Yes. No. We have all the software to do it, we have BIM, we are currently going through the training process, yes, we're getting … we've got a new architectural technologist to come in, especially to help us with our BIM strategy, and BIM software, and we've all got it, we've paid a lot of money for it, and nobody's using it in the office yet, so …' (Architect, supply chain position 3)*

> *'Because we're at design we're almost expected to have an understanding of BIM where, in reality, it's everybody, it's the estimating team, it's our procurement team, everyone's got to be able to buy in to it and understand that it's a process, it's not.' (Mechanical and electrical engineer, supply chain position 3)*

The evidence above provides a classic example of how the professionalisation of an industry forces organisations within that industry to behave in a manner in which they feel legitimate (Deephouse, 1996). An awareness of BIM is deemed to be absolutely crucial, whether it is in use or not. Those competing within the industry have been drawn to its implementation in order to feel parity with other similar organisations.

Technology and software outside the scope of BIM was not discussed in great detail; however one of the core difficulties expressed was with the scope and boundary of carbon analyses, this was supported by the following quotation:

> *'The problems you have with carbon is there's that many different data sets out there, different tools out there, which is the right one to use, if you use a different data set you come up with a different answer, if you use a different scope and boundary you get a different answer, these are issues that are fundamentally difficult to overcome.' (Participant E1)*

The level of technology and the number of data sets available makes decisions on which tool to use difficult, therefore a sense of inertia has evolved as it has become impossible to make an informed decision on use. There was a sense in the data of apathy towards technology outside of BIM due to the number of different tools and technologies and additionally the lack of appetite for it. Thus far there has been no governmental enforcement for carbon measurement systems implemented for use on building projects; there are simply unenforceable recommendations (HM government, 2012). There has however been governmental endorsement of the implementation of BIM, not primarily used as a sustainability tool but used for efficiency (Bynum, et al., 2012). The implementation of BIM could simply be coerced via governmental pressure (Cao, Li and Wang, 2014). In reality however the diffusion of such innovation requires a vast mix of supply chain actors which has been referred to as a 'product system' (Marceau et al., 1999). It is this system which ultimately provides inter-sectoral patters of innovation flow aided by the interdependence of organisations (Schmookler, 1966; Arditi et al. 1997).

If BIM was a legal requirement, all construction companies would be forced into using it. There was a unanimous consensus of the potential benefits that BIM could bring to the construction industry. In many countries including the UK there has been a leaning towards

the mandatory use of BIM in public projects, but only where appropriate (Cao, Li and Wang, 2014). The reference to government implementation was recognised in the data through references alluding to the governmental requirements for BIM:

> *'The Governments have said by 2016 all projects will be BIM level 2 as a minimum for Government related jobs.' (Participant C1)*

The governmental implementation of BIM was thought to be a significant driver for the uptake of the software as there was pre-emption that it could become a legislative requirement. The key problem with its full development is that it is only necessary to use it on government funded projects (HM Government, 2012).

> *'Well, if we look at BIM now, and what it's used for, it's required for every Government project, it's not yet required for every construction project.' (Consultant, supply chain position 3)*

The use of BIM on government projects is a coercive pressure in the sense that there is a requirement for it to be used from a higher body. To the extent of government funded projects it remains a pressure to enforce the use of BIM to aid efficiency measures. For the construction industry at large however it is not required and so therefore the pressure is lessened as the use and implementation of BIM remains advisory (HM Government, 2012). The limitations of coercive pressures even if they are implemented by governments are highlighted by the evidence above. The limitation is that in order to enforce implementation of new processes it must be industry wide and not simply for a select few. In order for collaborative networks to aid the development of low carbon decision making, all parties would need to be involved, by coercing only certain industry sections into adhering to particular developments; it enforces inertia regarding certain aspects of construction. Innovation is discouraged as a premium is placed on traditional goals disregarding the potential benefits of environmental foci (Blayse and Manley, 2004). Industry design and procurement standards mean that many new technological implementations will need to be designed around this:

> *'The idea is that with all the data that will be attached to the 3D models, and particularly with the way that umm … the process of design and procurement means that you have to bring forward much earlier in to the process a lot of the nailing down what something is.' (Architect, supply chain position 3)*

The concept of BIM could encourage low carbon decision making analyses to be performed from the conception of the project. Currently carbon analyses are often carried out

retrospectively (Poudelet et al., 2012). The design and procurement standards act as a coercive pressure. It was noted in the study that coercive pressure can act as a barrier to the implementation of sustainability. Companies aim to have an awareness of software such as BIM but fail to actually implement it on a significant level indicating an appearance of legitimacy as outlined below:

> *'Yes. No. We have all the software to do it, we have BIM, we are currently going through the training process, yes, we're getting ... we've got a new architectural technologist to come in, especially to help us with our BIM strategy, and BIM software, and we've all got it, we've paid a lot of money for it, and nobody's using it in the office yet, so …' (Architect, supply chain position 3)*

The example above highlights how coercive pressures can be effective at engaging companies to take on BIM. Government endorsement of the software has encouraged some companies to take on the software, pre-empting the potential for future legislative requirements. In the above case the participant implied that coercive pressures are not always positive as the expenditure associated with the implementation of BIM had been high and yet the software had not been used to its full potential. It seems that the appearance of legitimacy is sometimes more important than the full development of a product which may be due to the way in which construction cultures impact industry behaviour (Schein, 2006; von Meding et al., 2013).

In relation to environmental outputs, construction companies are often marketed on their green credentials but provide no visual evidence. The practice of marketing has led to an acceptance of 'greenwashing' the appearance of being green without providing evidence (Walker et al., 2008). Perhaps greater emphasis needs to be placed on evidence of these green credentials in order to be seen as a legitimate construction company. By working closely with others many will ultimately be able to acknowledge whether companies are in fact adhering to environmental concerns. The institutional pressures of others acquiring knowledge may influence supply chain actors to truly adhere to their expressed sustainability outputs due to fears of being seen as an illegitimate company (Tseng and Chou, 2011).

The implementation of technologies for low carbon decision making are subject to mimetic pressures (Bhakoo and Choi, 2013). Mimetic pressures directed towards the implementation of BIM however has been found to be much more complex when compared to other technologies. Compared with traditional construction innovations BIM involves organisational change for its implementation (Bhakoo and Choi, 2013). Additionally the use

of BIM has high investment costs and its value is often dependent upon external factors (Bryde at al. 2013) i.e. governmental influence.

Construction companies have struggled on how to address issues with specific relation to each project (Eastman et al. 2011). Differences between buildings create uncertainty in the construction industry as each project is individual (Clough et al., 2000). Differences in characteristics have been proven to be enough of an uncertainty to influence the adoption of BIM as companies within similar fields will aim to follow the trends of companies who are considered successful and similar in nature (Bhakoo and Choi, 2013). The findings did highlight evidence of mimetic behaviour but also highlighted that in some cases it did not aid business. For example participants expressed that they had implemented BIM in their business systems in order not to lag behind, however it was not being used:

> *'Yes. No. We have all the software to do it, we have BIM, we are currently going through the training process...we've paid a lot of money for it, and nobody's using it in the office yet, so …' (Architect, supply chain position 3)*

The data above shows how companies take on particular technologies in order to appear legitimate. It seems that at times when the implementation of a technology may not be the correct business decision, technology is implemented in order for the business to keep up and remain legitimate in its social group, imitating others (Fligstein, 1991). High capital costs have been outlaid for the implementation BIM and benefits have already been called into question. Low cost options may be much more effective, reducing monetary risk in future low carbon decision making strategies. When potential outcomes are uncertain, mimicking others has been acknowledged as a successful way to deal with the problem (Sarrina Li and Lee, 2010). Some design teams have foreseen a problem with overlooking BIM with forward thinking clients, who may require the use of BIM. Not being able to offer a BIM package may eliminate them from bidding for certain contracts, therefore appearing legitimate with the prospect of using BIM is a price paid for prospective work. Design teams expressed that they were *'expected to have an understanding of BIM'.* Additionally mimicry in practice for BIM implementation has not seemed to have taken hold due to supply chain fragmentation. Due to this fragmentation BIM is not seen as *'a joined up process.'* Thus indicating that company influence for software and technology uptake is not easy with current supply chain structures. They inhibit the flow of diffusion between construction supply chain actors (Kornelius and Wamelink, 1998).

The focus on technology is considered as a barrier to the development and diffusion of low carbon decision making. The focus on technology itself has presented a series of issues which have made successful calculation of carbon emissions problematic. One of the main issues with technological approaches is the assessment of the scope and boundary of calculation with different people choosing to include or exclude particular details of calculation (Asif et al., 2007; Ortiz et al., 2009). With various studies concluding different environmental impacts for each building stage, it has become nearly impossible for construction companies to agree on relevant technologies (Adalberth 1999; Kotaji at al., 2003; Gustavsson and Joelsson, 2010). So far no LCA technology or piece of software has effectively diffused. The supply chain structure could be held responsible for this as often communication (essential for diffusion) does not take place regarding such models and so therefore it is difficult to make decisions on scope and boundary of carbon calculation from the conception of the project. Current technologies exclude human decision making criteria, most of which could be attained via increased collaboration which is vital for the diffusion of innovation (Orlander, 2007; Ayuso et al., 2011; Bal et al., 2013).

In addition to technological based problems such as scope and boundary, the nature of the focus on technology has also proven to be a barrier to the diffusion of low carbon practices. For instance, the vast amounts of technological products available on the market have created wide ranges of products which all have distinct similarities. It is acknowledged that similarity of products is a key diffusion inhibitor and the introduction of a new product will require to be marketed as 'different' particularly in a saturated market (Gatignon and Robertson, 1985; Hill 1970). The problem with new products and innovations however is that they carry risk which is something the industry strives to avoid.

5.11 The effect of institutional pressure on the diffusion of innovation

In order to produce a framework for low carbon decision making institutional theory has been used to assess coercive, mimetic and normative pressures which are exerted on the supply chain. The assessment of such pressures has provided new insights into client power and the pressures which keep those powers in place (DiMaggio and Powell, 1983). The understanding of these pressures will enable a supply chain perspective of the issue of the restraints holding key supply chain actors their respective positions. It does not however highlight how these pressures impact on the diffusion of low carbon innovation and how this can be overcome.

The diffusion of innovations theory has been used to examine how low carbon innovations could move throughout the industry, in light of institutional pressures which may be impacting on low carbon strategy uptake. It has been suggested that the structure of the construction industry and the way it operates, i.e. short term contracts, price focus and the power dichotomies of the supply chain have made it difficult to form influential relationships (Songip et al., 2013).

The complexities and multidisciplinary nature of the construction industry make supply chain relationships difficult. Social theory has shown that the greater the number of people involved in a task the more difficult integration becomes (Simmel, 1902; Durkheim, 1933 and Blau, 1970). The linear format of the construction supply chain itself, coupled with the sheer volume of people involved in a single project tends to inhibit the development of communicative supply chain relationships. It is these relationships which could break down coercive and normative pressures (Cheng et al., 2001). The format of the chain is hierarchical in nature and prevents influential relationships from forming. It is difficult to collaborate in linear chains; therefore each section has been coerced into focusing on their own individual tasks, disregarding the potential of collaborative working.

The cornerstone of diffusion theory is the notion of collaboration and communicative processes (Rogers, 1971). Rogers' (1971) acknowledges the diffusion process is a channel for communication where information passes between social groups, or in this case supply chain actors. Collaboration occurring between different sections of the supply chain could encourage innovations to flow throughout the chain more smoothly, working on the basis that increased knowledge regarding innovation decreases risk and spreads awareness of innovative strategies (Rogers, 1971). Engaging supply chain actors in decision making promotes sustainability throughout the chain by increasing awareness (Persson and Orlnder, 2004; Bal et al., 2013; Ayuso et al., 2011).

Each thematic concept established from the findings was found to conform to institutional isomorphic pressures which have shown to impact the diffusion of innovation. The literature review and data highlighted that technological solutions to the emissions problem had primarily been marketed at architects and contractors, possibly due to the notion that low carbon choices are usually made at the design stage of a project. All studies suggest that low carbon choices are best made at the beginning of a project (Cofaigh, et al., 1999; O'Sullivan,

et al., 2004; Tsai, et al.,2011; Basbagill, et al., 2013). In reality however, the primary use of LCA tools is retrospective (Poudelet et al., 2012).

The research has found that one of the key failings of LCA tools is in the marketing. Tools have primarily been targeted at the design market, which has limited influence over the implementation of low carbon strategies. The research argues that the tools and strategies should be directed at the client and key innovator. In terms of diffusion adopter categories, innovators account for just two percent of businesses. With those able to innovate in short supply, innovators must be strategically targeted and influenced, something which the LCA market appears to have missed by trying to implement LCA at the design stage with those less able to implement the use of low carbon innovation on projects. Normative and coercive pressures have placed the client in the most powerful and influential position (Caio, Li and Wang, 2014). The supply chain structure also makes influencing the client exceptionally difficult due to top-down approaches (Hartmann et al., 2008). Marketing technologies towards designers has not led to the successful diffusion of low carbon innovation as those below the client felt that their level of influence was minimal. Additionally they are being held in position by coercive and normative pressures which are forced through the client as the traditional focus on time and cost remains (Ciao, Li and Wang, 2014; Abanda et al., 2013).

The data highlighted that a lack of collaboration was a key factor in the poor development of low carbon decision making due to poor information exchange rates (Janda, 2011). Poor information exchange can also be attributed to the linear supply chain which inhibits collaborative processes, essential for the diffusion of innovation (Rogers, 1971). The findings confirmed in line with the literature that the focus needs to remain on the concept of managing data collaboratively through human based strategies (Kurul, et al., 2012). Widespread integration would enable information sharing to occur between all supply chain sections, disseminating information directly relating to carbon outputs. With increased knowledge, the client alongside others in the supply chain could theoretically make much more informed decisions by increasing the reach of carbon data collection.

5.12 Proposed network supply chain framework

As suggested a network based supply chain could be most beneficial for the implementation of low carbon decision making processes (Cheng et al., 2011). The cyclical supply chain approach shown in Figure 5.2 would ultimately encourage a shared learning environment

which is considered essential for the uptake and diffusion of new strategies (Peansupap and Walker, 2005). Shared learning is particularly relevant to the fact that technology has failed perhaps due to the emphasis on firm centric use (Koh, et al., 2013). Expanding the range of communication flow could aid carbon data information exchange and increase diffusion rates as greater numbers of people become aware of the potential benefits of low carbon decision making. Figure 5.2 has been produced and developed in order to provide a potential solution to the low carbon emissions problem in view of the data findings. The network framework shoen in figure 5.2 could reduce client power via a multi-directional information flow system which creates more pathways of influence between all supply chain actors (Cheng et al., 2011). By increasing influential pathways and collaboration processes the diffusion of innovation is more likely to occur as greater number of supply chain actor are exposed to new strategies (Gatignon and Robertson, 1985). Additionally, this system would theoretically modify the impact of isomorphic pressure throughout the chain. Where the client was previously exposed to external coercive and normative pressures such as cost, in this Framework the client would also be subjected to further coercive and normative pressures via the homophilous influence zone through multi-directional information and influence exchange. For example, key actors' such as the design and management team in a construction project would have the ability to promote change through communicative processes. Increased communication could encourage the client to use low carbon strategies, leading to an increase in mimetic isomorphic pressure as success can be seen due to the close proximity of supply chain actors. Those outside of the homophilous zone may also benefit from their ability to have greater impact on the client, increasing the notion of 'weak ties' which aid the spread of diffusion (Granovetter, 1973).

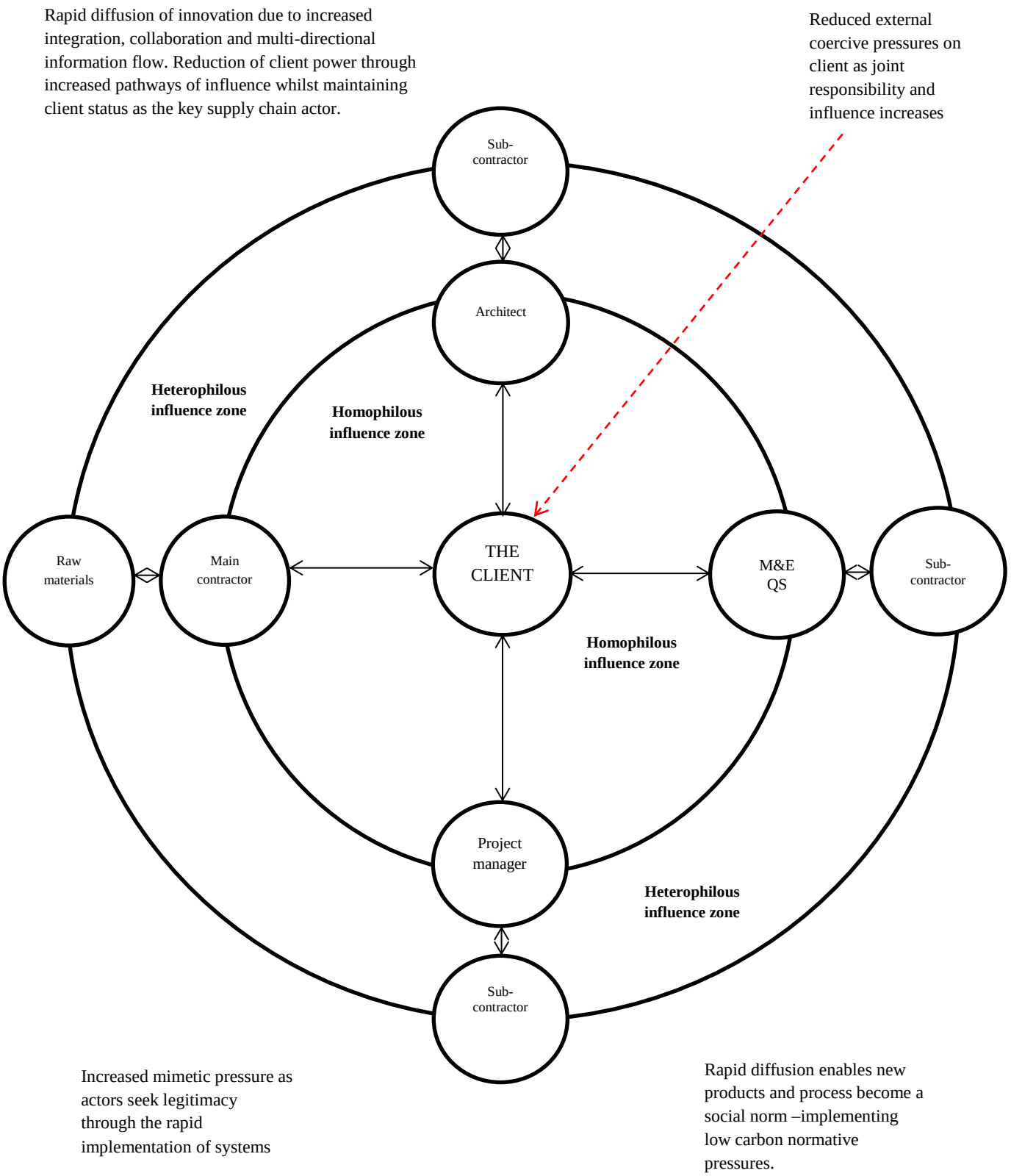
The importance of weak ties and the ability of low carbon strategies to diffuse across supply chain actor boundaries can also be explored in this framework (Granovetter, 1973). The importance of reaching those on the outskirts of a business network is exceptionally important to the development of new low carbon strategies. Development of such strategy could potentially be achieved through heterophilous influences which are influential beyond the standard social set (Gatignon and Robertson, 1985). The framework would enable influences to stretch beyond the standard norms set by institutional pressures by increasing multidirectional information flow. In this network supply chain client power is broken down and supply chain entities have the potential to influence each other regarding low carbon decision making. Influential pathways and multidirectional information flow cannot occur

within a linear supply chain. The two way information flow among similar and dissimilar individuals provides potential for diffusion. Client power is decreased by increasing the influence that others have on the client, however the client remains at the centre of the project.

Diffusion itself is thought to provide social change within an organisation as the adoption of innovation will often have social consequences (Rogers, 1971). This was evidenced in the data by the design team implementing sustainable measures due to client requirements. The supply chain has been found to inhibit diffusion as diffusion will always occur within social boundaries (Rogers, 1971; Gatignon and Robertson, 1985; Gouwes and Reed van Oudtshoorn, 2011). Evidence of this was provided by the allusions to individual supply chain actors working in their individual sectors (Cheng, et al., 2001; Kornelius and Wamelink, 1998: Abbot, 1988). These boundaries would need to be broken down in order for widespread supply chain diffusion of low carbon innovation, as innovation depends entirely on the interactions between individuals (Littlejohn and Foss, 2008).

The potential for diffusion of low carbon innovation decision making strategies can be improved by using network collaborative supply chains (Cheng et al, 2001). The diffusion of low carbon strategies would be diffused via the ability to influence (Gatignon and Robertson, 1985). Influences enable ideas to spread rapidly between different groups which is where the use of the network supply chain could help, particularly when reaching external business networks (Gatignon and Robertson, 1985). Reaching unknown business networks can push new ideas beyond normative social barriers, thus innovation could theoretically spread throughout a supply chain (Gatignon and Robertson, 1985). The outcome of the research has shown that widespread adoption of low carbon information exchange procedures could enable project teams to make more informed low carbon decisions.

Figure 5.2 Proposed supply chain framework for low carbon decision making



5.14 Summary

Low cost human centred approaches to data sharing could increase diffusion rates via influential collaborative pathways presented by network supply chains (Cheng et al, 2001). The data highlighted that extensive isomorphic pressures placed on the client and the linear format of the supply chain are the core sustainability barriers in the low carbon construction agenda. Cost based and contractual pressures force the client to follow certain pathways to which they are restricted. Often any implementation of new technologies requiring capital cost outlay will be disregarded. The data highlighted that others down the supply chain would like to implement low carbon decision making practices but felt that they were hindered by client rigidity which was promoted by the supply chain. In view of this, theoretically a focus on collaboration throughout the construction supply chain could encourage greater influential relationships to form. Knowledge sharing could enable those below the client to perhaps influence the client on low carbon decision making without incurring high costs. Encouraging influential collaboration could help to diffuse new low carbon decision making prospects, provide the impetus to take on environmental causes and additionally provide legitimacy in the future development low carbon buildings.

Chapter 6.0 - Conclusion

6.1 Introduction

Chapter 6.0 will provide an overall conclusion to the research. It will outline the main implications of the study and provide summarised answers to the research questions reflecting on the empirical data discussed in Chapter 5.0. It addition, it will assess the practical application of the research whilst outlining the original contribution to knowledge, and addressing the study limitations. The final sections of the chapter will present potential areas of future research and concluding comments.

6.2 Study context

The research was sponsored by Phlorum Ltd. in conjunction with funding from the Centre for Global Eco Innovation. The purpose of the research was to understand the reasons why, despite the abundance of technological solutions to construction emissions, CO_2 has continued to rise in the construction industry on an annual basis (Strategic Forum for Construction, 2010). Phlorum had previously produced an LCA product and wanted to understand how it could be improved and positioned in the market in view of the limited success of other products (Heijungs et al., 2009). As an industry funded Ph.D the company were inclined to seek practical outputs which were an essential part of the research. After assessment of the literature there was evidence of a knowledge gap emerging in the human behavioural implications of low carbon decision making. The lack of literature which addressed carbon emissions from a behavioural perspective i.e. using collaborative processes or supply chain integration (Koh et al., 2013) led Phlorum to strive to address the potential for a collaborative carbon analysis system based on behaviour. The need for positioning a new carbon analysis tool as 'different' appeared to be essential in the uptake of innovation (Gatignon and Robertson, 1985), and applying a behavioural based approach to carbon analyses appeared to do this.

The management of life cycle data from a collaborative perspective was found to be lacking in current research (Koh et al., 2013). The failure of existing LCA technologies in lowering emissions in the construction industry has suggested that the knowledge gap appears to be the disregard of the supply chain (Koh et al., 2013). The construction supply chain encompasses all activities throughout an entire construction process and is conceived at the beginning of the project when the greatest collaboration takes place (Basbagill et al., 2013). Currently,

environmental analyses are often considered as an additional output, left until the end of the project. They are generally carried out retrospectively using the information available that is often limited (Poudelet et al., 2012). At this point of assessment the environmental impact of the building is likely to be fixed. The key outputs of the research highlighted that the most important focus areas in integrating low carbon decision making systems could be reduced to several core components. These included, the supply chain, client power, collaboration, risk and cost.

The implementation of current LCA technology is considered to be high risk in construction as the preference remains on tried and tested methods (Blayse and Manley, 2004). In an industry which strives to reduce risk, the concept of using innovative and often high cost emissions analysis products with no enforcement or guarantee of success was not well received. The concepts outlined in the study context (i.e. supply chain structure, technological focus, collaboration, cost and client power) are thought to have hindered the implementation of low carbon construction strategies. These key areas therefore were addressed in view of the literature evidence, through DiMaggio and Powell's (1983) institutional theory and Rogers' (1971) diffusion theory which acted as theoretical lenses. The analysis enabled an understanding of whether collaborative supply chain networks could aid the ability of the construction industry to overcome institutional barriers and diffuse low carbon innovation strategies via collaborative supply chains. The application of a practical output was in line with Phlorum's specifications for a model or framework which could differentiate itself from other LCA systems.

One of the key assessments of this study is that the implementation of environmental analysis from the beginning of the project is critical for the successful formulation of low carbon strategy. A system whereby supply chain actors have joint responsibility for providing data could transcend the institutional boundaries enforced by linear supply chain structures. A networked and integrative system could be highly beneficial for lowing project emissions. Supply chain actors are more exposed to emissions data through collaborative working and so therefore can hypothetically make more informed low carbon decisions.

The research has shown that the emphasis placed on technological solutions has induced a sense of environmental inertia regarding emissions calculation. There has been an abundance of technology which has presented the following issues for construction companies. Firstly construction companies are not familiar with the products and widespread adoption would

require training at extra cost. Secondly, there is no enforcement to use or measure carbon emissions and thirdly the client's emphasis on capital cost would see the implementation of any novel concept for emissions control as a further financial outlay. Added costs are avoided to remain within tight budgets and retain profits (Yang and Chen, 2015). Therefore any new low carbon concept would be required to simultaneously transcend yet embrace traditional construction values such as cost.

By addressing institutional pressures, the concept of legitimacy emerged as a particularly influential subject for a highly competitive industry (Kumaraswamy and Dulaimi, 2001). The findings showed that for some the appearance of being a 'green' company at any cost was a legitimate practice, whereas for others, remaining legitimate meant disregarding environmental issues such as carbon emissions. To develop an understanding of how low carbon innovation could become an integral part of construction, research questions were established to understand whether collaborative networks could aid the adoption and diffusion of low carbon decision making practices.

6.3 The research questions

The following three questions were examined in this research to understand whether collaborative supply chain frameworks could transcend institutional barriers and aid the diffusion of low carbon decision making strategies in construction. Each question is answered below.

RQ1. How can low carbon decision making strategies diffuse throughout the construction supply chain?

During periods of change and uncertainty it is possible to adapt through innovation (Miller and Friesen, 1982). Once the innovation is conceived it must then diffuse in order for it to become successful and achieve widespread adoption. The analysis found that the areas of primary importance when addressing diffusion were centred on collaborative working and integrated approaches. Collaboration, influential relationships, implementation of networked supply chains, integrated procurement systems and client led innovation were found to be critical in the diffusion of innovation in the construction industry. Lack of collaboration through fragmented chains has been held in place by institutional isomorphic pressures which are impacting on all areas of the chain. It is these pressures which are retaining traditional supply chain structures.

Traditional construction procurement systems have been found to inhibit the diffusion of innovation by fragmenting the supply chain (Kumaraswamy and Dulaimi, 2001). These procurement systems have been enforced by supply chain structures which insist on individuality and self-protection through fear of contract loss (Blayse and Manley, 2004). The linear supply chain formats held in place by the construction procurement system are now considered a social norm. Normative pressures are the defining factors which hold these systems in place, preventing the diffusion of innovation. Additionally, the design build contract in construction means that limited people are collaborating at any one time, however, as this contract is considered to be the most effective construction method, institutional pressures are now holding these systems in place as tried and tested methods of efficient building practice (Xia et al., 2013; Blayse and Manley, 2004).

The lack of collaboration evidenced in the discussion was shown as a distinct barrier to the diffusion of innovation. Collaborative approaches are also held back by the configuration of the supply chain in its hierarchical and linear format (Rosinski et al., 2014; Dirix et al., 2013).The top down approach in cases of environmental management has not been successful (Dirix et al., 2013; Diringer, 2011).The structure of the chain inhibits diffusion as the chain actors work individually and so therefore it takes a long time for others to recognise success. Currently the supply chain is seen as a polarised entity whereby the ends of the chain do not communicate and information is pushed through several actors before reaching the client. In view of this, one may question whether the client is fully informed, indicating the potential for the network supply chain framework (Dubois and Gadde, 2002). A networked supply chain framework could encourage an interdisciplinary approach to low carbon decision making which often requires input from many different areas of the chain (Kiker et al., 2005). Integrated supply chains and networked structures lead to greater levels of collaboration and influence which are crucial in the diffusion of innovation (Rogers, 1971). Furthermore, increasing integration encourages new strategies to move beyond the social network which is generally where an innovation will initially reside.

Due to the current formulation of the supply chain the client will always be seen as the key actor in the chain as they hold the greatest power through finance. Institutional pressure placed on the industry for many years has held the client in the place of key decision maker and innovator (Ryd, 2014). In view of this, if an increase in collaborative and networked supply chains was configured in the industry, the client must lead and so therefore diffusion

starts with the client (Kilinku, Ozturkn and Yitmen, 2015). For effective diffusion to continue however, influential relationships and collaborative networks are essential for information flow, the establishment of success and ultimately the diffusion of innovation. All of which can be achieved by shifting the influence of institutional pressure. Only then can innovative low carbon decision making processes diffuse effectively. Coercive isomorphic pressure would be placed on the chain encouraging mimetic isomorphic change and encouraging low carbon buildings to become a social norm, rather than an additional requirement.

The analysis of the findings highlighted that the current position on low carbon strategies in the construction industry is a product of uncertainty. Many technologies have been developed in order to measure CO_2 emissions, however thus far none have seen profound and widespread adoption (Heijungs et al., 2009). In order for a novel low carbon strategy to take hold, it must encounter a number of factors in order for it to diffuse. The evidence highlighted that the most positive way to achieve this is through collaborative and integrated approaches. Increasing the reach of influential relationships was found to be one on the most important factors for the spread of innovation (Dubois and Gadde, 2000; Gatignon and Robertson, 1985).

The proposal put forward in this research is to implement a networked supply chain for the diffusion of innovation in the construction industry (Cheng et al., 2001). Relationships could be strengthened increasing pathways of influence and collaborative processes. In a networked supply chain success could be viewed and client power and competition could be reduced as emphasis on the collective is increased. One of the key arguments found in the literature regarding diffusion was the notion of loose couplings (Dubois and Gadde, 2002). Some of the most influential factors in the diffusion of innovation are the prospects for homophilous and heterophilous influences in the adoption of novel practices (Gatignon and Robertson, 1983). Acknowledgement of these influences was an essential component in the development of the proposed supply chain framework which could facilitate the diffusion of low carbon strategy. In essence the diffusion of low carbon innovation could be achieved by increasing communication channels and pathways of influence, both of which are vital components of the proliferation of innovative practice.

RQ2. How can the implementation of low carbon decision making strategies improve a firm's legitimacy in the construction industry?

The criticality of legitimacy is manifest in businesses. Organisations seek to remain legitimate in order to be considered for projects and do so by adopting similar practices to other businesses within their socially constructed networks (Baretto and Baden-Fuller, 2006). The term legitimacy was used in conjunction with the understanding of institutional isomorphic pressure, whereby the definition was understood as the perception that particular activities carried out by organisations are either desirable or a socially constructed norm (Suchman, 1995). Currently low carbon construction is not seen as a legitimate practice. The consideration of environmental inertia as a legitimate practice has acted as a barrier to the diffusion of low carbon innovation, one which is not easily overcome. Analysis of the findings has initiated an understanding of how the implementation could become a legitimate practice through institutional pressures and the diffusion of innovation (DiMaggio and Powell, 1983; Rogers, 1971). The analysis of the findings highlighted that in order to appear legitimate, low carbon decision making practices were not required.

Lack of enforcement, perceived high costs, risk and a lack of demand have all contributed to the perception of illegitimacy whilst the construction industry continues to contribute heavily to anthropogenic emissions (Strategic Forum Constructing, 2010). The noted high cost perception has ultimately inhibited construction companies from moving outside of the range of capital costs in the tendering process, fearful of appearing illegitimate through environmental foci (Feminias, Kadefors and Eden, 2009). One suggestion to the movement towards environmental applications promoting legitimacy was thought to be how well educated and informed people were about low carbon decision making and sustainability practices (Janda 2011; Akintoye et al., 2000). Accordingly, in order for the construction industry to see the implementation of low carbon projects as a legitimate practice, a solution may be found in education and the ability to inform the industry regarding the benefits of long term costs with sustainable buildings. Once people are informed of the benefits then they are more likely to take on innovation, particularly if it is successful, thus implementing low carbon strategy becomes a legitimate practice.

The notion of similarity has contributed to the difficulties associated with the implementation of low carbon strategies in construction. Inertia towards environmental application is considered to be legitimate. The findings highlighted that the traditional values of cost,

quality and time based emphasis (Abanda et al., 2013) were held in place by coercive and normative pressures. As a traditional industry, over time, coercive pressures such as cost have inhibited the client from viewing low carbon construction as a legitimate practice. The findings presented in this research proposed that the expansion of influence via the proliferation of business networks could encourage the supply chain to view low carbon construction as a legitimate action. Viewing success and increasing communicative channels can make a practice legitimate, greater numbers of people wish to take on an innovation if it is acknowledged as a success in the wider business community.

Collaboration and integration is critical for low carbon decision making innovations to become legitimate in construction practice. Only through increased communication can the true benefits of low carbon buildings can be seen. Once a higher number of companies strive for the implementation of these buildings, pressure is placed on non-conformists to adhere to environmental concerns. New practices will gain momentum as isomorphic pressures are placed on the 'late majority' and 'laggards' who fear the prospect of becoming illegitimate as success can be seen via close proximity working systems of network supply chains (Cheng et al., 2001; Rogers, 1971). Although Rogers (1971) states that the individual in the chain will make individual decisions based on adoption, the isomorphic pressures felt by a company who feels they are missing out will establish the drive for the implementation of legitimate practices (DiMaggio and Powell, 1983). Ultimately the implementation and diffusion of innovation throughout the supply chain will be encouraged through mimetic isomorphic pressure, as collective knowledge will be used to eliminate the perception of risk and remain legitimate (Brouthers, O'Donnell and Hasjimarcou, 2005).

The proposed supply chain framework (see Figure 5.2), has the potential to increase collaboration. Working in close proximity with other supply chain actors could increase the possibilities of influence, viewed success and diffusion of that success. Once collaboration has increased and low carbon strategies are considered as a legitimate practice, further members of the supply chain will strive to emulate it until it becomes an institutional social norm. At this point the innovation will have diffused as a critical mass is reached and legitimacy of that practice is confirmed, a process driven by influential pathways and collaborative working strategy (Rogers, 1971).

RQ3. What provides the impetus for construction companies to take on low carbon decision making innovations?

The existing literature and empirical findings on low carbon stimuli has been relatively unclear. There appeared to be several factors which could impact on a company's incentive to introduce low carbon strategies. The research has highlighted several factors working independently and symbiotically which provide the impetus for a sustainability drive. Without question however, the client was found to be vital in providing the impetus for the initial uptake of low carbon processes, indicating that the predominant force in implementing any forward thinking low carbon technology is the client (Ryd, 2014). Any action reverberated down the supply chain is generally implemented by the client. However, the client is also subjected to a number of institutional pressures which compel them to behave in particular ways; predominantly via coercive and normative pressures i.e. regulation, cost and or social norms (Cao, Li and Wang, 2014).

Coercive pressures associated with the development of low carbon systems presented themselves in the form of government backed software such as BIM (HM Government, 2012; Azhar, et al., 2009). Although BIM is not primarily targeted at sustainability, its ability to create highly effective and efficient construction projects would eliminate waste, thus reducing carbon. With the BIM process greater collaboration could take place and decisions can be made early, from the conception of the project (Cofaigh, et al., 1999; O'Sullivan, et al., 2004; Tsai, et al., 2011; Basbagill, et al., 2013). The BIM system was also conceived by a company who are trusted in the industry. Trust may encourage more people to take on this product simply because of the company who produced it. If legitimacy is acquired by lowering emissions through government backed systems then this will provide the impetus for companies to take on low carbon decision making strategies.

External and inter-organisational schemes can also provide the impetus for companies to take on low carbon strategies. An example of this in the data was found in the use of Environmental Product Declarations (EPDs). The data highlighted that these had been used by a particular company in order to overcome the reliance on cost and competition. They provided a standardised system outlining the environmental costs of supply chain products, providing traceable carbon pathways whilst simultaneously addressing finance (Rodriguez-Melo and Mansouri, 2011). In this instance the EPD acted as coercive pressure as companies who wished to work together on particular contracts were forced to provide EPDs in order to

outline supply chain impacts (Bovea, Ibáñez- forés and Agustí- Juan, 2014). For those working within this particular company, standardised systems acted as coercive pressure in order to implement low carbon projects.

Thus far the construction industry has seen a lack of incentives for the implementation of low carbon decision making strategies, particularly when the focus on cost, time, quality and the client remains (Abanda et al., 2013: Monghasemi et al., 2015). The perception that environmentally responsive business strategies cost more has been a significant restriction for the development of low carbon practices. With this perception clients have continued the drive for low cost and durable buildings using tried and tested methods (Feminias, Kadefors and Eden, 2009; Blayse and Manley, 2004). Additionally a lack of education and influence for construction clients has meant that this perception has continued to be embedded in the industry (Janda 2011; Akintoye et al., 2000). In cases where sustainability had been a top priority, the impetus had been provided by the client requesting sustainability analyses. In these cases the onus was on producing a highly sustainable building and the predominant concern was not cost, re-iterating the importance of client power and influence.

In the proposed networked supply chain framework, the client is exposed to more supply chain actors, increasing the potential influence that lower supply chain ranks could have on the client (Persson and Orlander, 2004; Jeffrey, 2009). The empirical findings suggested that even at times when other supply chain actors such as architects wanted to implement carbon calculation, they were not able to due to their lack of influence on the client. If the client is exposed to low carbon strategy across the chain on a regular basis, the client may be more heavily influenced to build low carbon buildings. In this case the impetus for low carbon construction could come from the desire for sustainability by any of the organisations in the construction supply chain. Currently in most cases it is only able to come from the client.

6.4 Contribution to knowledge

Literature supported by the empirical findings noted that the construction supply chain is not conducive to sustainable and low carbon building design or innovative processes (Miozzo and Dewick, 2004; Pries and Janszen, 1995). The client holds much of the power and is subjected to a series of institutional pressures. These institutional pressures coupled with the linear and hierarchical supply chain structure has inhibited the conception and diffusion of innovative low carbon construction practices. The contribution to knowledge in this research

is the extension of emissions analysis by using a supply chain perspective. Knowledge is furthered through the explanation of how institutional pressures experienced by all supply chain actors, impact on the diffusion of low carbon innovation in construction. A network supply chain framework has been developed as a unique structure for understanding the problems faced in construction LCA, and how collaborative systems can aid the development of low carbon innovation in construction supply chains. The framework furthers our understanding of the key barriers faced when implementing low carbon strategy in the construction industry. It facilitates greater understanding of the impact of institutional pressures and client power, addressing the way they inhibit the full implementation and proliferation of novel low carbon practices. By overlaying DiMaggio and Powell's (1983) institutional theory with Rogers (1971) diffusion theory, the pressures exerted on the supply chain could be explained. The factors which inhibit the diffusion of novel concepts could also be addressed alongside potential solutions which could aid the diffusion low carbon practice.

By combining institutional theory and diffusion theory the research was able to illustrate how coercive, normative and mimetic isomorphic pressures act as both enablers and inhibitors for the diffusion of low carbon innovation, developing a novel supply chain approach to CO_2 life cycle analysis. By addressing the phenomenon of LCA failure through the analysis of qualitative data and using institutional theory and diffusion theory as theoretical lenses, a practical and theoretical output was formulated. The outcome of the theoretical analysis enables an assessment of the prospect of using collaborative supply chain networks to lower emissions through information sharing strategies. The potential for using collaboration via networked supply chains has been highlighted in the empirical data. The research has provided a contribution to the body of knowledge surrounding emissions analysis which has previously been heavily focused on software based approaches in the construction industry.

By engaging with both institutional theory and diffusion theory a new theoretical perspective has been developed furthering the understanding of why diffusion of novel concepts in institutionalised industries is difficult and how these barriers can be overcome. The novel practical application of a networked supply chain based on the key concepts of diffusion such as collaboration, communication and influence could be beneficial for multidisciplinary environmental data sharing (Kiker et al., 2005). Not only has the research provided a novel theoretical concept for institutional behaviour and innovation diffusion, the research has also

furthered the development of supply chain management in sustainability via the application of novel supply chain frameworks. Both concepts have provided grounding for further research into the diffusion of low carbon strategy and the barriers that must be overcome for successful integration into institutionalised supply chains.

6.5 Practical Contribution

The theoretical context underpinning this research has enabled the potential for a practical application for this enquiry. The acknowledgement of the associated supply chain structure problems, collaborative inhibitions and the understanding of institutional pressures which have shaped construction project outcomes; i.e. reliance on the client have enabled the potential for an advisory solution based on networked supply chains.

Figure 5.2 illustrates how such a system may be achieved. The potential for a collaborative network supply chain system whereby client power is dissipated could have positive implications for collaborative and influential relationships to take place (Rogers, 1971). The research argues that a networked supply chain structure would facilitate a system whereby the client can be more heavily influenced by those with a greater awareness of sustainability (Cheng et al., 2001). The outcome of a networked system could produce more knowledgeable clients who could therefore make more informed decisions on low carbon design. In addition, the client would be subjected to a range of isomorphic pressures from other supply chain actors, potentially encouraging them to be more favourable towards sustainability as the success of others was seen within the supply chain.

The research posits that the practical application of a reconfigured supply chain could be implemented on a construction project, opening up collaborative systems for the dissemination of carbon data. The development of such a supply chain could also have practical application for the development of operations management research in sustainability. Low carbon innovations and concepts could be targeted at the client who has the power to implement. The collaborative process could have beneficial impacts on both design and environmental outputs with higher levels of information sharing from a multidisciplinary perspective – essential for environmental decision making (Basbagill et al., 2913; Kiker et al., 2005). Furthermore, it may provide a practical contribution to understanding client power in the construction supply chain. Understanding the impact that client power has on other supply chain actors may ultimately encourage them to try and

implement change. Having the ability to influence the client more to encourage the development of low carbon buildings may provide business advantages.

A final contribution was to the sponsoring company's business strategy. The LCA tool previously developed by Phlorum was unlikely to prove lucrative with the current saturated market. It was understood at the beginning of the research that each technology measuring carbon emissions is sold as a product. In view of this, Phlorum acknowledged the potential for selling carbon measurement as a service, constructing networked supply chains as a measurement system. Additionally, the work carried out has enabled them to implement a movement towards offering CSR based services, whereby companies can have their overall sustainability assessed thus highlighting external impacts of the research.

6.6 Research limitations

All research is subjected to a series of limitations which with reviewed consideration could be improved. The research presented in this thesis is no exception. The qualitative focus of the study means that the empirical findings are subjective which require interpretation by the researcher who acts as the research instrument. External legitimacy is difficult to implement (Clissett, 2008; Patton, 2001; Goladshini, 2003; Bakoo and Choi, 2013). The process of interviewing produces highly interpretive data (Denzin and Lincoln, 2000). Additionally, the use of qualitative enquiry also presents challenges with research bias due to researcher participant relationships and the difficulties of separating the research from personal thoughts (Chenail, 2011; Casey, 2004, Kapoulas, 2003; Bogdan and Biklan, 1982).

The sampling procedure may also be acknowledged as a research limitation as theoretically the sample should investigate the entire population of an industry (Acharya, 2013). The distinct inability to do this means that participants are selected based on availability. The sample however, must be able to achieve the research aims and provide validity which can be difficult when using human subjects (Uprichard, 2011). Due to the challenges faced using human participants, it was considered to be unlikely that different research methods would yield different results. The participant selection procedures based on availability made it difficult to find construction clients to take part. As the key supply chain actor, further understanding of their perspective would have been highly beneficial for the research, however, as their refusal was widespread; this provides an interesting area of further research

as their reasons for refusal to take part were unclear. All qualitative research will suffer from limitations however steps were taken to reduce these limitations as explored in chapter 3.0.

Although this research provides a potential solution to how low carbon data can be shared by overcoming sustainability barriers, and providing a system boundary, it does not fully address how emissions could be calculated. As the research purpose was to remain distant from mathematical calculation, this has not been covered. In retrospect, if carbon emissions analysis was requested, in order for all supply chain actors to provide data they would all need to adhere to a calculation format. In order for such a system to be fully integrated, the calculation procedure would need to be addressed for future prospects.

6.7 Recommendations for future research

The research presented in this thesis provides a novel contribution to emissions analysis through the application of supply chain networks, addressing the impact of institutional pressures on the diffusion of low carbon innovation. It does not provide a full solution to all emissions calculations problems, but provides a starting point for future research development in carbon emissions analysis using supply chain based methods. Future research could be carried out in operations management, building sustainability or life cycle analysis fields to develop supply chain approaches to sustainability. The research initiates a system boundary for carbon analyses as the supply chain which can encompass all direct and indirect emissions (Koh et al., 2013). Potential future areas of research are addressed below.

Firstly, the use of collaborative networked supply chains would most likely require a collaborative platform which may require a technology such as BIM. The implementation of BIM would also be subject to the institutional pressures in the implementation of innovation as discussed in Cao, Li and Wang, (2014). The construction industry's thirst for technological solutions, evidenced in the findings suggests that the essence of full responsibility for emissions analysis exists in the merging of technology and supply chain oriented solutions. Further research could provide a perspective into understanding how the implementation of both could work practically, particularly with BIM's collaborative emphasis (Azhar et al., 2009). The use of BIM could be particularly relevant with the governments drive for BIM implementation (HM Government, 2012). The product of collaborative BIM could provide an opportunity to understand how technology and social science could be merged to accommodate the potential for future legislative trends. Such research could be carried out using a mixed methods approach combining quantitative data on the adoption of BIM and its

effectiveness, with qualitative data in the form of interviews to provide meaning to the quantitative studies, enhancing the investigation process (Krivokapic-Skoko and O'Neill, 2011).

Secondly, in order for the networked supply chain structure to be implemented into a fully working model, further research could be carried out on how the network supply chains could aid mathematical calculation of emissions. Although the purpose of this research design was to distance the outputs from mathematical calculation, it does not provide a full picture of how data analysis for emissions would be carried out in order for the dissemination of information between supply chain actors. It does however suggest a system boundary by which all actors can work creating uniformity, a problematic area with existing calculation methodologies (Ortiz et al., 2009). The combination of technological and supply chain approaches for the future of low carbon building design and decision making processes must be addressed fully to provide complete carbon analysis in supply chain systems. A quantitative research approach for this area of further research would enable a calculation of carbon emissions whilst simultaneously facilitating it through networked supply chains. The freedom of information exchange between supply chain actors would enable an assessment of the impact of homogenous calculation methods for carbon in collaborative supply chains systems.

Finally, the extension of institutional theory by combining diffusion theory could be applied to other institutions. The impact that institutional pressures have on the diffusion of innovation in other industries could provide interesting theoretical applications. Its use in other industry research would enable robust testing of the theory and further its development. Research into the impact of institutional pressures in technology adoption for example has been carried out in health care research (Bakoo and Choi, 2013). Furthering research in other industries to encompass how institutional barriers may be overcome to implement change could have positive consequences for the future development of implementing new products and processes into a wide range of industries.

6.8 Final comments

Chapter 6.0 has provided a conclusion to the research by recapping the study context, answering the research questions in brief, providing an assessment of the contribution to knowledge, study limitations and potential for future research. A supply chain framework

which has potential for practical application in industry has been produced, concluding that that the key factors inhibiting the development of low carbon construction is the linear format of the supply chain, which retains traditional hierarchical construction formats and client power. By furthering knowledge in collaborative supply chains, a novel application for behavioural based emissions analysis has been formulated as grounding for further work on lowering emissions in construction and other institutionalised industries.

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