Social network analysis of knowledge transfer in sustainable office building projects in the UK and Germany
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SOCIAL NETWORK ANALYSIS OF KNOWLEDGE TRANSFER IN SUSTAINABLE OFFICE BUILDING PROJECTS IN THE UK AND GERMANY

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This thesis is dedicated to my mother

Dr. med. Ute Schröpfer

who was diagnosed with Alzheimer’s at the beginning of this PhD. Even in moments when she forgets who I am, she is quite certain that I should finish this PhD.

ABSTRACT

Sustainability is fundamentally transforming construction industries worldwide, resulting in an increased complexity of construction projects with a more divergent set of actors involved. A seamless transfer of knowledge between these actors is required. The gap between the performance of green buildings as designed and as built could be interpreted as an indication that this transfer is not immaculate. Nowadays almost every actor involved in the construction process claims to strive for sustainability. However, the way they perceive and translate it into practice varies widely between different project participants. Therefore a better understanding of how knowledge on sustainable construction is transferred and adopted is needed. A subsequent enhancement of this process could support a certain standard of sustainable building quality. Previous research indicated that social networks influence knowledge transfer (KT), as knowledge is personal and KT takes place through interaction of individuals. Moreover, social network analysis (SNA) provides the means to map the knowledge flow in a project environment and thus enables an understanding of how to enhance it. As a result SNA was used to compare KT practices in construction teams delivering office buildings to sustainable building standards in Germany and the UK.

A literature review led to the establishment of a conceptual framework that characterizes the KT process. This was used to inform the research design, data collection and analysis. The research was carried out using a multiple case study approach. The data collection tools were mainly questionnaires with a combination of quantitative, qualitative and social network data. The data was analysed using a combination of descriptive statistics, cross tabulations, content analysis and SNA. The findings were used to revise the conceptual framework.

The findings showed a lack of awareness and knowledge of sustainable construction. Moreover, analysis of the data concluded that KT on sustainable construction is influenced by so-called general enhancers/ inhibitors, such as age group and job level, and social network characteristics. Furthermore the results suggest benefits could be derived from employing a sustainability manager as a key contact and to enhance KT on sustainable construction.

This research contributes to literature on KT in sustainable construction project teams from a social network perspective. It is the first of its kind comparing KT in construction teams delivering sustainable office buildings in Germany and the UK. The framework is the most important output of this research in terms of both contribution to knowledge and practice and can be used to support the examination of KT in sustainable construction projects. Furthermore this study facilitates the understanding of knowledge contents and types of sustainable construction knowledge.

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ABBREVIATIONS

BRE	- Building Research Establishment
BREEAM	- Building Research Establishment Environmental Assessment Method
DGNB	- Deutsche Gesellschaft für Nachhaltiges Bauen
DGNB	- Deutsche Gütesiegel für Nachhaltiges Bauen
ENEV	- Energieeinsparverordnung
KM	- Knowledge Management
KT	- Knowledge Transfer
LEED	- Leadership in Energy and Environmental Design
RICS	- Royal Institution of Chartered Surveyors
SN	- Social Network
SNA	- Social Network Analyses
SME	- Small and medium sized enterprise
WBCSD	- World Business Council of Sustainable Development

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CHAPTER 1

INTRODUCTION

1.1. The Focus on Sustainability in the Built Environment

Sustainable development as a concept has been gaining increasing attention across various sectors since the Brundtland Commission Report in 1987 (Pitt *et al.,* 2009). Since then many new policies, legislation and initiatives that are related to environmental performance and sustainability have emerged in lots of countries around the world (Dixon, Keeping, Roberts, 2008).

Sustainability is holistically defined as economic prosperity, environmental quality and social justice (Elkington, 1998). This is often referred to as the three pillars of sustainability or the triple bottom line definition of sustainability (Ellison, Sayce, 2007). Within the built environment all three aspects are equally important, as buildings have a major impact in environmental, economic and social terms (UNEP, 2007; in Dixon, Colantonio, Shiers, 2008). Besides the direct ecological impacts of buildings, significant resource reductions can be achieved at relatively affordable costs compared with other industries (Nelson, 2007).

Buildings account for about 40% of global energy use, approximately 25% global water use and circa 30% of greenhouse gas emissions (WBCSD, 2012). Measuring and reducing greenhouse gas emissions, especially carbon dioxide plays an important role in delivering sustainable buildings. About half of UK's carbon emissions derive from buildings, 27% from residential and 17% from nondomestic homes (DCLG, 2009). There is a variety of governmental targets especially on carbon emissions of buildings. Current research on how to reach these targets largely focuses on residential buildings, although commercial buildings emit similar amounts of CO2, with offices representing the largest sub-sector of commercial buildings in most countries (WBCSD, 2009). Therefore this study focuses on office buildings.

Due to rising energy prices and more affordable greening technologies there are also attractive returns on green building investments (Nelson, 2008). On average green buildings cost only about 2.5% more than their conventional counterparts (Galbraith, 2008). Yet the capital cost of sustainable buildings is likely to reduce as a result of increasing demand and hence availability of sustainable building materials (Dugard, 2007), depending on the country. Unfortunately most people still rather acknowledge the economic benefit of energy saving costs only, while neglecting the increasing evidence that sustainable buildings have the potential to deliver benefits in economics, marketing, government, employee relations and risk management (Yudelson, 2008). They return higher rents, offer faster letting, secure greater occupancy and generate higher resale value (Smith, 2006; Lützkendorf, 2007; Pitt *et al.,* 2009). Green buildings are designed to conserve natural resources and improve human health. They can deliver a variety of public benefits related to resource conservation, indoor air quality, carbon emissions and air pollution (Pivo, 2008). On the occupier side, besides lower operating costs, a significantly increased occupant productivity and well-being represent the main advantages of sustainable buildings (Dixon *et al.,* 2009). In addition there is a reduction of risk factors, including marketing, financing and securing political authorization to develop (Yudelson, 2008).

In addition to the benefits of sustainable commercial buildings the future has to be considered as well. Engelhardt (2010) puts forward that without sustainability the buildings will soon be considered to carry certain risks and valued accordingly. Lorenz and Lützkendorf (2011) go along with this by claiming that sustainability is part of any valuation, including conventional buildings. The higher risks that are associated with buildings that are not sustainable include faster obsolescence and tenant fluctuation that have to be considered and priced accordingly (ibid).

Many companies recognised the benefits of 'going green' in order to highlight their corporate social responsibility (Nelson, 2012). This type of consumer behaviour of market leaders will set new future standards (Nelson, 2008) and implies that the environmental impact of buildings is becoming important to all players in the property market (Hinnells *et al.,* 2008). Hence sustainability is fundamentally transforming real estate market dynamics, as the nature of product demanded by tenants, constructed by developers, required by governments and favoured by capital providers is also changing (Nelson, 2008), and thus becoming more complex (Meyers, 2008). In 2009, Nelson declared that the then recession will only slow, but not fundamentally change the real estate market shifting towards sustainability worldwide. In 2012 this statement was proved to be true as more and more investors consider sustainable performance of buildings when selecting assets (Pink, 2011; Nelson, 2012). Additionally buildings are far more efficient than a decade ago, which is also due to rating systems (ibid).

One of construction industry's responses to the sustainability agenda is the development of rating methodologies for assessing the sustainable performance of buildings (Atkinson, Yates and Wyatt, 2009) against a wide range of criteria, and awarding certificates such as BREEAM in the UK and DGNB in Germany. However, even after more than a decade of discussions, the commercial real estate sector could not agree on common standards (Nelson, 2012).

Although there seems to be a need for sustainable buildings, barriers constraining the growth of sustainable construction have been identified as for instance length of payback period, initial investment costs and lack of supply (Dixon *et al.,* 2009). Even, if lack of demand is not a key barrier, occupiers believe that the additional costs of sustainability and undersupply are restricting market growth (Dixon *et al.,* 2009). Regarding the UK construction industry Kurul *et al.* (2011) identified further barriers towards delivering sustainability as the plethora of initiatives and policies and the silo-based structure of the industry.

Moreover Nelson (2007) states that as every new product, green buildings bring risks along with the rewards. The main risks can be associated with less experienced construction firms through underestimated construction costs, product missing the mark or inability to deliver on promises. Furthermore there are considerable regional variations in the adoption of sustainable construction practices (Nelson, 2008). For that reason the question remains whether the green building delivered is as sustainable as designed. Most sustainability assessment methods still rather measure the design stage (Ding, 2008), while some environmental impacts are better measured by actual performance (Nelson, 2012). There have been several studies comparing the actual performance of sustainable buildings with their intended one, revealing differing results (Hinge *et al.,* 2008; Robinson, 2008). For instance, a New Buildings Institute study in 2008 compared intended energy efficiency with actual energy performance of LEED certified projects and revealed that the results differed widely from the design intentions. This proves a need for linking sustainable design intent to operational performance (Robinson, 2008) and investigating the barriers preventing this. The UK government acknowledged the performance gap and partially funded a seven year research project on post occupancy in 1995 called Probe (Cohen *et al.,* 2008). Another more current project is the Carbon Buzz, were designers can report the predicted and actual performance of buildings (Stevenson, Bordass, 2011). Furthermore the Usable Buildings Trust aims to better connect client, design and building teams in order to help them to be more focused on the built result (ibid). Hinge *et al.* (2008) put forward that the reason for the performance gap can be found in the user behaviour, neglecting the role of the construction phase. Whereas Bordass *et al*. (2004) argue that there are many potential reasons for the performance gap that can be divided into four main categories. This study concentrates on the third one, the construction stage, in order to explore how knowledge on building sustainably is transferred between professionals and operatives, due to the significance of this transfer in the delivery of sustainable buildings.

- Slippage during initial estimation
- Slippage during design development
- Slippage during construction and commissioning
- Once completed

Nevertheless, the reasons given seem to assume that each stakeholder group has the capacity and knowledge on building sustainably. Yet, despite the proximity of legal targets, e.g. in the UK, coming gradually into force, still only a small number of professionals in the industry possess the specialised knowledge and experience to design and operate sustainable buildings successfully (Williams, Dair, 2007; Nelson, 2007; WBCSD, 2009). Moreover there seem to be difficulties in the process of putting this new knowledge on how to build sustainably into practice (Ugwu, 2005). Previous research has shown that for professionals the main barriers to adopt sustainable building techniques are personal know-how and commitment (WBCSD, 2009), which reflects not only a lack of training and education in relevant techniques (Dixon, Colantonio, Shiers, 2008), but also personal commitment and a supportive environment and business acceptance.

Although all project team members have to constantly absorb new technology and techniques in order to remain competitive (Fong, 2003), sustainability engagement is higher for senior staff, and generally in larger organisations (Dixon, Colantonio, Shiers, 2008). Delivering truly sustainable buildings requires engagement of staff at all levels through the translation of strategic policy initiatives to concrete design guidelines and actions at the micro level (Ugwu, 2005). Current practices in designing for sustainability (Bierkeland, 2002; in Ugwu, 2005), and the way construction companies connect, deploy and manage this sustainability knowledge in order to deliver the design, need to be analysed in order to develop effective means of this translation (Ugwu, 2005). This evaluation will result in a better understanding of the divergent ways in which different actor groups perceive and translate sustainability into practice (Rohrbacher, 2001; Williams, Dair, 2007).

In addition to the translation issues, the level of complexity in projects, where the ultimate goal is to deliver a ‘green building’, is higher than in standard ones (Myers 2008). This is due to the increased number of people involved, but also because of the nature of technical knowledge required. Furthermore some sustainable buildings require high-tech components, which are supplied by specialized companies, e.g. renewable energy solutions. Hence the supply-chains are more distributed and intricate than before (Williams, Dair, 2007). Thus various sorts of new services and consultancies become more important, as a high level of expertise is required for solving the complex problems of ecological optimization (Rohrbacher, 2001; Williams, Dair, 2007).

The increasing importance of sustainability has vital consequences not only on the technological practice of construction industry, but also on its structure and its communication channels (Rohrbacher, 2001). As a result, a better co-operation and integration of various stakeholders is required through enhanced KT from project inception to completion (Rohrbacher, 2001; Williams, Dair, 2007).

1.2. Knowledge Transfer on sustainable construction and the Social Network Analysis Approach

In all organisations, the politics of knowledge sharing is an issue (Egbu, 2004). Within the built environment, where the need for innovation and improved business performance requires the effective deployment and utilization of project knowledge, the need for strategic knowledge management is being acknowledged as well (Kamara *et al.,* 2002). As sustainability issues are changing the definition of tasks within the construction sector (Kamara *et al.,* 2002), difficulties might emerge because of fast technical changes (Cohen, Levinthal, 1990), resulting in the requirement of adjusted KM strategies.

There is a very diverse range of professions within the sector, all carrying different kinds of knowledge that contribute to the project. As the diversity of knowledge is one of the main factors for innovation (Cohen, Levinthal, 1990), its effective management plays a vital role in gaining competitive advantage (Sharkie, 2003). This is of greater significance in a project based sector such as the construction industry, which is challenged by the need to capture and transfer knowledge within an environment of temporary multidisciplinary project teams (Kamara *et al.,* 2002). Each project is unique in terms of design and construction, and faces many restraints due to limited space, increasing complexity, limited budgets, tight programmes and the constant demand for facility innovation (Fong, 2003). Characteristics such as professional silos with their own knowledge and language render KT in such teams even more difficult (Bresnen *et al.,* 2003). Additionally it has to be acknowledged that the various actor groups on a construction project use different tools for transferring knowledge, i.e. for instance architects transfer knowledge differently than bricklayers.

There is considerable research on sustainable buildings and the technological solutions which help to achieve the required performance levels (Halliday, 2008). However, there is still a lack of understanding on how knowledge can be transferred and widely adopted between professionals and operatives, despite the significance of this transfer in the delivery of sustainable buildings. This might result in green buildings, which are not performing in a sustainable way, although they are assumed to do so. Hence these buildings could be an unproductive investment, and moreover do not support achieving governmental targets, such as cutting down carbon emissions in the long run. As previously argued recent studies have revealed a gap between the designed intent and the built outcome (Bordass, Leaman, 2013). Thus in order to put new sustainable building techniques into practice it is especially important to understand how knowledge can be transferred and widely adopted between all relevant professionals and operatives. This study suggests that enhancing this special KT between all project participants could provide one of the means to deliver a certain standard of sustainable building quality.

Fernie *et al.* (2003) indicate that knowledge is personal, and therefore knowledge sharing takes place through the interaction of individuals. Hence social community plays a vital role in enhancing or inhibiting KT (Bresnen *et al.,* 2003). As knowledge is a set of shared beliefs constructed through social interactions and embedded within the social contexts, Fong (2003) declares that social networks are the most important vehicle for knowledge exchange, with team members deeply reliant upon colleagues, friends and ex-colleagues as resources for generating knowledge. Moreover Nahapiet and Ghoshal (1998) claim that social networks are a valuable source for new knowledge. Within a project environment the personal knowledge of whom to contact in order to receive the required knowledge, appears to be most important (Bresnen *et al.,* 2003). As a result success seems to depend rather on interpersonal connections, than technological mechanisms (ibid).

There is considerable research on the importance of social networks for knowledge sharing and creating, as well as their enhancing and inhibiting effect on it (Fong, 2003; Bresnen *et al.*, 2003). However, Bresnen *et al.* (2003) stress that research on social mechanisms that support knowledge sharing is still limited. While Inkpen and Tsang (2005) state that there is a theoretical gap in the research where the key concepts of networks, social capital and organizational KT interconnect. In addition Seufert *et al.* (1999) point out, that KT and networking are a very powerful combination for knowledge management, while only few studies examine how different dimensions of networks facilitate the transfer of knowledge among their members. Furthermore Hansen (2002) suggests research combining concepts of network structure and relatedness in tie content regarding specialised knowledge. These suggestions were taken into account and applied to the area of sustainable construction. This rationale forms the basis of this study and is further explored in Chapter 4, where the network approach and its relevance to KT on how to build sustainably are discussed in detail.

In summary, this study aims to close this gap in research, regarding examining KT in project teams dealing with specialised knowledge on sustainable construction with a social network approach. Moreover this research facilitates the understanding of knowledge contents and types of sustainable construction knowledge. In addition the findings, and especially the conceptual framework as one output of this study, could be used by project teams to manage and transfer knowledge more efficiently. Furthermore the findings contribute to the literature on knowledge transfer particular from a social network perspective. The research is the first of its kind comparing knowledge management practices in construction teams dealing with sustainability issues in Germany and the UK.

1.3. Research Aim and Objectives

The main aim of this research project is to investigate the extent to which social networks can influence knowledge transfer within project teams delivering new office buildings to sustainable building standards in Germany and the UK.

The objectives for achieving this are:

- To identify the key concepts in the area of knowledge transfer and social networks.
- To identify factors that influence knowledge transfer.
- To develop a conceptual framework based on these key concepts and factors.
- To test the conceptual framework in practice.
- To make recommendations on how to use the framework in order to enhance knowledge transfer in practice.

1.4. Methodology and Methods

Pragmatism was chosen as the methodological basis of this project, as it is most likely to offer the opportunity to influence the way construction industry conducts its business. This study adopted a multiple case study approach as its research strategy (Bryman, 2008), in order to generate an intensive and detailed examination of the whole complexity of KT. The unit of analyses is one sustainable construction project. Additionally the comparative design of the study provided a better understanding through comparison of two or more cases (ibid). Thus two case studies in the UK and three in Germany were used to compare KT within project teams involved in current construction projects of sustainable office buildings. As argued in section 2.4.1 these are two leading countries in sustainable principles and comparable in size and level of construction volume. The selected construction projects were those trying to achieve a comparable score in BREEAM or DGNB as discussed in section 2.4. Moreover the projects had to fulfil certain selection criteria, presented in section 5.4.1, such as being rewarded with the appropriate pre-certificate, new constructions and under construction in 2011/12.

Figure 1.1 presents how the aim and objectives were approached in due course of this research. In keeping with the aim and objectives, stated in the previous section, a conceptual framework was developed, based on key concepts in the domains of KT and social networks, including influencing factors. These factors were identified through a comprehensive literature review. The conceptual framework was tested in practice through case study data. The constant exchange of ideas and discussions with practitioners from the field led to a continuous modification and improvement of the data collection tools throughout the whole process of data collection.

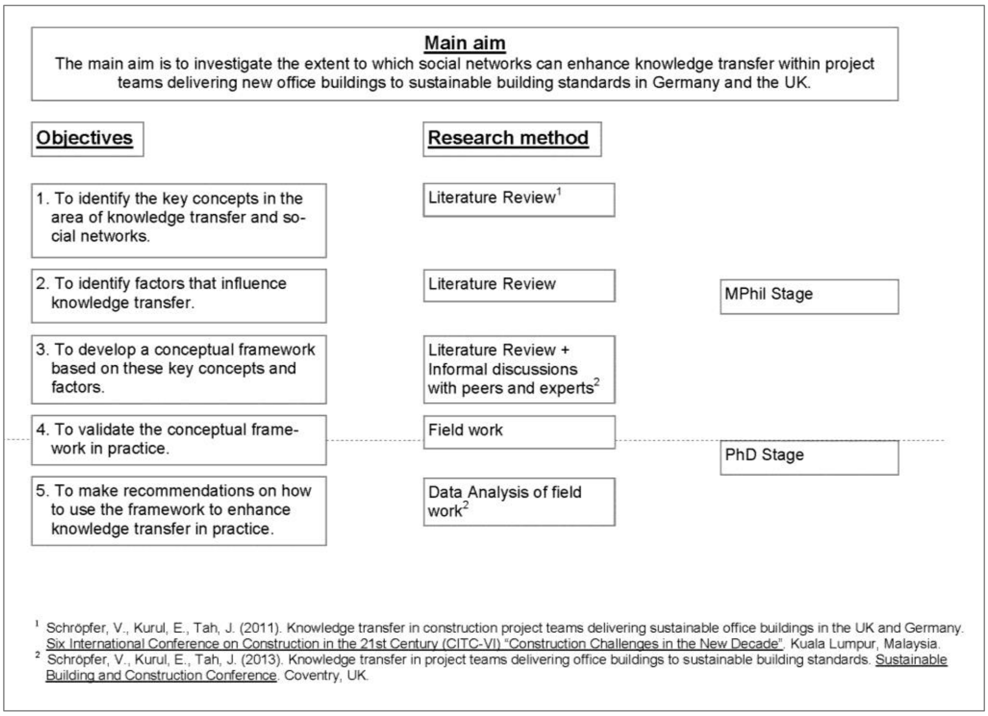

Figure 1.1: Research Approach

The chance to use various sources of evidence, which is also vital for the process of triangulation, is an important strength of case study data collection (Yin, 1994). Therefore three different methods of data collection were regarded to be sufficient and necessary to explore in-depth the rich issues found in construction projects and their management (Bryman, 2008). The data collection tools were mainly questionnaires with a combination of quantitative, qualitative and social network data. These were backed-up with literature, documentation sources and a small set of participant observation data, when available.

In terms of analysis, three different methods were used. Social network analysis was used to map the social networks of each case study, i.e. construction project, in order to understand how knowledge is transferred through it. In addition to this, content analysis of the qualitative questionnaire and participant observation data, plus descriptive statistics facilitated a deeper understanding and allowed linking the results, such as the exploration of the tie content.

1.5. Summary of Key Findings and Contribution to Knowledge

This research contributes to literature on KT specifically from a social network perspective. In doing so it responds to the gap in knowledge pointed out in section 1.2 and argued by various authors, i.e. to combine concepts of network structure and relatedness in tie contents regarding specialised knowledge (Seufert *et al.*, 1999; Hansen, 2002; Bresnen *et al.*, 2003; Inkpen and Tsang, 2005). Overall the results showed that the examined variables, i.e. general enhancers/ inhibitors and social network characteristics influenced each other and KT on sustainable construction. The findings, as discussed in detail in section 8.2 are the following:

The findings of all five case studies showed that the educational background defined the job level. Moreover the variable job level/educational background was found to be the one with the greatest influence on other variables and KT itself. Here the awareness towards sustainability, the training received, actor centrality, i.e. being a knowledge expert or consumer, the knowledge subject area required and the KT methods preferred were all influenced by job level/educational background of the KT participant. These links were more prominent in case studies with more job levels represented by respondents. This confirms the need to up-skill practitioners in the field as argued by various authors (WBCSD, 2009; Kurul *et al.,* 2011; Thomson *et al.,* 2010; Rodrigues *et al.,* 2012). Furthermore the findings add to the discussion of how the job level of KT participants affects the success of KT.

The awareness towards sustainability was overall higher in the German case studies. Furthermore findings of two case studies (UK1, GE2) indicated that the level of awareness is influenced by the job level of the actor, as previously stated, i.e. operatives and supervisors were less aware of sustainability. Additionally the age group of the UK participants influenced whether they received special training on sustainable construction. This suggests improving the vocational training and better implementing sustainable principles. Moreover it proposes to better inform all project participants and especially the construction workforce of the importance of sustainability and the use of sustainable materials/technologies in order to raise the overall awareness and support a coherent knowledge vision.

An overall lack of agreement whether special training on sustainable construction is needed was observed in all case studies. Furthermore German respondents were more certain how to describe such training, whereas UK respondents were confused what it might involve. Slightly more training was received in German case studies, while training needs were higher in the UK case studies. The national differences in this point can be explained with the strong legal background in Germany, regarding the implementation of sustainability principles. This goes back to 1976 with the first energy savings ordinance, as presented in section 2.4.1.

The KT process can be influenced by the age and job level of the participants due to them preferring different KT methods. Moreover the results showed a difference in KT methods used to request and to transfer/ receive knowledge. Additionally literature on KT methods for transferring tacit knowledge was confirmed through the results as well (Haldin-Herrgard, 2000; Egbu, 2004).

The findings of this research confirm literature (Thomson *et al*, 2010), as to suggest employing a sustainability manager as a key contact and to enhance KT on sustainable construction as a gatekeeper.

Moreover the results on the duration of the KTs give an indication of the average time needed to transfer knowledge on sustainable construction, i.e. up to ten minutes, even though just in the context of four case studies.

Furthermore this study facilitates the understanding of knowledge contents and types of sustainable construction knowledge. The following three subject areas were determined and knowledge types allocated:

- sustainable materials – explicit, know-what
- sustainable technologies – explicit and tacit, know-what and know-how
- techniques - tacit, know-how

The preferred knowledge source in four case studies was a colleague. This indicates that strong trust based relationships are needed to transfer the knowledge requested on sustainable construction. The network density of all five case studies is relatively low, showing sparse networks regarding KT on sustainable construction. Results on the tie contents show materials and a combination of all three subject areas as the most requested knowledge. As a result the findings indicate that large amounts of tacit knowledge were transferred through strong ties in sparse networks. This confirms literature (Granovetter, 1973; Augier, Vendelø; 1999) in regards that strong ties are needed to facilitate a tacit KT. Yet, this outcome also questions existing literature and shows a need for more research on the matter of network density, tie strength and tacit KT.

The framework is the most important output of this research in terms of both contribution to knowledge and practice. The findings confirm that the framework can assist researchers examining KT in sustainable construction projects in its entirety, whereas practitioners in the field could use the framework to support the KT between the various participating companies in sustainable construction projects.

1.6. Thesis Structure

The remainder of this thesis is organized in eight chapters. Figure 1.2 provides an overview of the thesis structure.

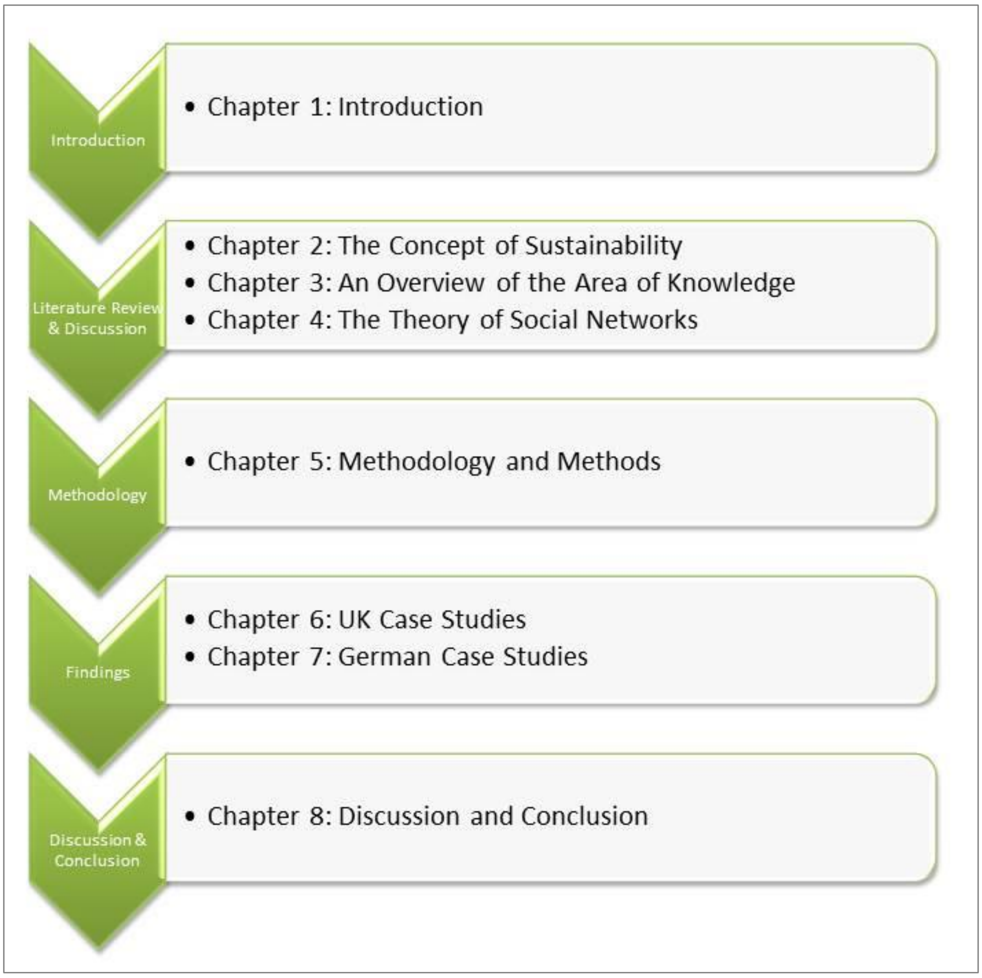

Figure 1.2: Thesis Structure

Chapter 2 reviews and critically discusses literature on sustainability within the built environment. The emerging need for design performance of sustainable buildings to be delivered in use seems to be in contrast with more and more evidence that some buildings do not perform according to the design intent (Bordass, Leaman, 2013). This performance gap could be interpreted as an indication that the KT between all project participants involved is not immaculate. Capturing and transferring knowledge from one stage of a building's lifecycle to the next is already difficult, with a considerable knowledge loss occurring during this process (Wallbank, Price, 2007). Additionally sustainability issues render this even more challenging, as they change the required knowledge and add new knowledge.

As a result Chapter 3 provides an overview of the area of knowledge management and transfer. Different types of knowledge to be found in literature are identified and applied to the field of sustainable construction. Three subject areas of knowledge emerged through sustainability issues in the built environment were determined as sustainable materials, technologies and techniques. A combination of explicit and tacit knowledge as to know-what and know-how were allocated to these areas. Moreover it is further explored in Chapter 3 how KT between the various practitioners can be enhanced. Several ideas of key concepts in the area of KM were adapted as the basis of a conceptual framework on knowledge transfer. The chapter concludes by presenting and discussing general KT enhancers/ inhibitors found in literature.

Previous research indicates the influence of social networks on KT. Therefore Chapter 4 explores the possibilities social networks could offer to enhance KT on how to build sustainably, in order to overcome the performance gap between sustainable design intent and built result. Various social network models and concepts combined with KT are discussed in terms of their relevance to the problem statement. The concepts drew attention to numerous factors which influence KT. The chapter concludes by identifying these influencing social network characteristics.

Chapter 5 presents the research methodology and methods chosen for this research. The chapter begins with a justification of pragmatism as the appropriate epistemology. The second part introduces the conceptual framework developed in due course, in accordance with the third research objective. The third part of this chapter introduces the case study approach, while the fourth part presents the data collection tools chosen. The fifth and last part describes the data analysis process including a justification of the selected tools.

Chapter 6 gives an overview of the findings of the two UK case studies, while Chapter 7 presents the ones of the three German cases studies. In Chapter 8 the main research findings of all five case studies are discussed in the context of existing literature. Moreover a revised framework after analysis is presented. This is followed by concluding this thesis with how the aim and objectives were addressed,and contribution to knowledge made, limitations of the research, as well as suggestions for further research.

1.7. Conclusion

This chapter has presented the context and rationale of the study through giving an overview of the background regarding sustainability in the built environment and the need for quality sustainable construction. Moreover the performance gap between sustainable design intent and built outcome was articulated as one of the main barriers towards sustainable construction. Therefore this research aims at showing possibilities to enhance KT between the various actor groups on a construction project in order to provide a means to overcome this gap. Additionally the chapter has highlighted the gap in knowledge in regards to approaching KT on sustainable construction from a social network perspective, and applying a comparative research design in terms of the UK and Germany rooted in the pragmatist paradigm. This chapter then proceeded by presenting the aim and objectives set out in order to close this gap. Furthermore the chapter gave a summary of the approach taken, including the methodology and methods applied in this study. Thereafter the key findings and contribution to knowledge were briefly presented. The chapter concluded with an outline of the thesis structure.

The following chapter presents the context of this study by reviewing literature on the concept of sustainability.

CHAPTER 2

THE CONCEPT OF SUSTAINABILITY

2.1. Introduction

Chapter 1 introduced briefly the background of this study, the problem statement, research aim and objectives and methodology adopted. The purpose of this chapter is to elaborate more on the basis and context of this research. Furthermore this chapter presents the argument why this study focused on new office buildings aiming for a sustainability certificate in Germany and the UK.

This chapter is divided into four parts. The first is a general introduction of the concept of sustainability. The second section focuses on sustainability in the context of the built environment, i.e. benefits and barriers of sustainable buildings, and how the property market has been transformed by sustainability issues. The reasoning for focusing on Germany and the UK, followed by a detailed description of sustainability certificates as one possibility for defining sustainable buildings, especially BREEAM and DGNB, are presented in section three. The final part discusses knowledge on sustainable construction, as this was identified as one of the main barriers towards the delivery of good quality sustainable construction. This part narrows down to the main focus of this research as to how this expert knowledge can be widely transferred and adopted by the various practitioners in the field.

2.2. Defining Sustainability

Although it is commonly assumed that the global movement of going green is a recent one (Robinson, 2008), the concept actually goes back 300 years, as Gertis *et al.* (2008) state that the term 'sustainability' was first used at the beginning of the 18th century in Preußen. Hans Carl von Carlowitz (1645-1714) first invented this term in relation to forestry, meaning that there should not be more tree-felling than re-growing of trees (Erenz, Grober, 2013). This was eventually determined in the 'Allgemeinen Wirtschaftsgrundsätzen der preußischen Staatsforstverwaltung' in 1894. Hence Germany developed the first concept and legal basis for sustainability worldwide (Müller, 2011). Dugard (2007) elaborates further on Europe being the cradle of sustainability, by stating that Europe was clearly a 'green' leader before the United States. Robinson (2008) goes along with this by putting forward that sustainability was Europe's logical and voluntary choice, due to natural resource constraints, compared with for instance North America.

More recently sustainable development as a concept has been gaining increasing attention across various sectors since the Brundtland Commission Report in 1987 (Pitt *et al.,* 2009). Furthermore, many new policies, legislations and initiatives that are related to environmental performance and sustainability have emerged in numerous countries around the world (Dixon, Keeping, Roberts, 2008). Such developments mainly followed the Rio de Janeiro Summit in June 1992 and the South African summit in 2002 (Ugwu, 2005).

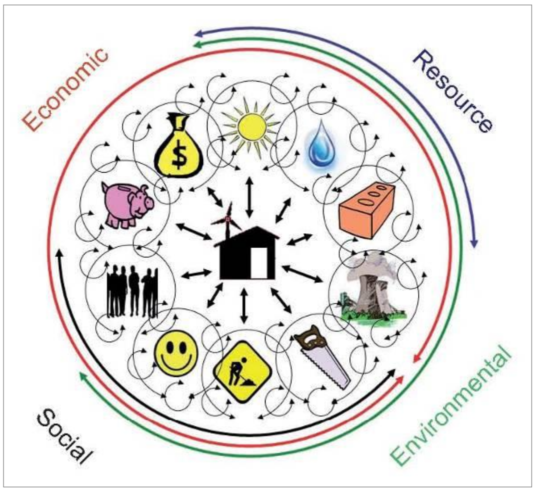

Figure 2.1: The triple bottom line definition of sustainability in the built environment (Atkinson, Yates and Wyatt, 2009)

A holistic definition for sustainability is provided by Elkington (1998) as economic prosperity, environmental quality and social justice. This is often referred to as the three pillars of sustainability or the triple bottom line definition of sustainability (Ellison, Sayce, 2007). This holistic definition of sustainability combined with the early thought of resource protection is illustrated in Figure 2.1. Within the built environment all four aspects are equally important. This is evident in the UK Green Building Council's (2008) definition of sustainable buildings as: 'resource efficient, with zero or very low emissions, contributing positively to societal development and well-being, to the economic performance of their owners/occupiers and to national economic development more generally.' As a result the following section will describe the meaning and importance of sustainability in the context of the built environment and how the industry and market changed according to it, respective is still changing.

For the purpose of clarity, the expressions 'green' and 'sustainable' are used synonymously in this thesis. In the literature 'green' is mostly used in Asia, especially Japan (WBCSD, 2007), the USA (Dixon, 2009) and partly in Germany (Lützkendorf, 2008), whereas 'sustainable' is used more in Europe (WBCSD, 2007).

2.3. Sustainability within the Built Environment

On average humans living in urban settings spend up to 90% of each day inside of buildings (Lützkendorf, 2007). Hence the quality of the built environment influences their health, comfort, security and ways of cooperation with each other. Moreover climate change requires an adaptation of buildings with regards to improved insulation, resistance against storms, hail, flooding and other extreme weather conditions (ibid).

There seems to be a fast growing need for rating methodologies to demonstrate the environmental performance of all our activities, ranging from personal carbon foot printing tools to complex sustainability assessments and standards of components, buildings and entire cities (Atkinson, Yates, Wyatt, 2009). Within the built environment measuring and reducing greenhouse gas emissions, especially carbon dioxide plays an important role in terms of delivering sustainable buildings. About half of UK's carbon emissions derive from buildings, 27% from residential and 17% from non-domestic ones (DCLG, 2009). Moreover buildings account for about 40% of global energy use, approximately 25% global water use and circa 30% of greenhouse gas emissions (WBCSD, 2012; UNEP, 2009 in Nelson, 2012).

In many countries environmental policy, particularly on carbon dioxide emissions, is beginning to impact on the commercial property market (Hinnells *et al.,* 2008). An example can be the European Committee for Standardisation (CEN), which developed standards for the 'integrated assessment of environmental performance of buildings' based on a life cycle approach (European Commission, 2004; cited in Atkinson, Yates, Wyatt, 2009). Specific areas covered, include frameworks for the assessment of environmental performance, social performance, economic performance and a general framework for the integration of these (ibid). Moreover the Energy Performance Certificates affected all European countries (Ellison, Brown, 2011).

In the UK context, environmental policies were developed relatively late compared to other European countries, such as Germany. The Labour party introduced several policies regarding carbon emissions, where zero carbon targets have to be met by 2016 for residential buildings and 2019 for non-domestic ones. However, the Coalition later on down-graded the zero-carbon homes criteria in terms of no compulsion on user-emissions to appliances (Porrit, 2011). In Germany the issue of CO2 was already addressed in the Mid-Nineties. Hence, current German policies do not only focus on energy issues, but also aim to support innovation and investment in the green building sector (Hegner, 2008).

Most research focuses more on residential buildings, although commercial buildings emit similar amounts of CO2. Moreover, offices represent the largest sub-sector of commercial buildings in most countries regarding floor space and energy use (WBCSD, 2009). This leads to the assumption that the impact of office buildings on the environment in developed countries is larger than the one of residential buildings. Moreover research has shown that investors do believe that offices are the property sector, which will encounter the most impact from sustainability issues (Keeping, Rawstron, 2010). This is supported by Pink (2011) who stated that about half of all certified sustainable buildings in Germany at that time were offices. As a result this study focuses on office buildings. Therefore the following couple of sections present various aspects of commercial properties related to sustainability, such as their benefits and how they changed market behaviour and which barriers they encounter.

2.3.1. Cost Premium and Payback Period of Sustainable Office Buildings

Besides the direct ecological impacts of buildings, significant resource reductions can be achieved at relatively affordable costs within the built environment, compared with other industries (Nelson, 2007). Rising energy prices and more affordable greening technologies lead to attractive returns on green building investments (Nelson, 2008). But how high are the average additional costs for sustainable buildings? There seems to be a general lack of agreement on cost premium and payback period of sustainable buildings. Smith (2006) determines the cost premium from 2 to 5%, while Dugard (2007) stipulate that it is between 0 to 5%. This goes along with a study sponsored by the US Green Building Council, which found out, that on average green buildings cost only about 2.5% more than their conventional counterparts (Galbraith, 2008). However, the capital costs of sustainable buildings are likely to reduce as a result of increasing demand and growing availability of sustainable building materials, hence a change in the supply chain (Dugard, 2007). In 2007 the Investment Property Databank launched a UK Sustainability Property Index which is still rather new and hence limited in the amount of data (Rodrigues *et al.,* 2012).

While there is a certain payback period, as RICS confirmed the relationship between property value and sustainability in its 2005 ‘green value’ study (Dugard, 2007), the financial case remains unclear for many professionals (Nelson, 2007). According to the RICS study (Dugard, 2007) and Smith (2006), the average of the payback period is four years. While Nelson (2007) estimates the amortization period of green buildings between 20 and 30 years and therefore much longer than the typical investor's holding period. At the same time Yudelson (2008) sets the median as approximately seven years. There are many more differing opinions on the payback period, probably due to a current lack of data and experience in the valuation of green buildings over a long period of time (Nelson, 2012; Rodrigues *et al.,* 2012). Furthermore, the cost of green building materials have decreased over time, as more manufacturers incorporate sustainable building materials in their product lines (Smith, 2006). This makes it even more difficult to build-up usable statistics for valuation of sustainable buildings in the short term, as they become cheaper over the years, until they eventually will reach a standard price.

Lorenz and Lützkendorf (2011) report a slow progress on this matter. In 2007 the Vancouver Valuation Accord was signed by RICS UK and the Appraisal Institute USA amongst others in order to improve the understanding, knowledge, education and practice about valuation and sustainability. Moreover Germany revised its valuation order in 2010 making it obligatory to consider energy efficiency in every standard valuation (ibid). Nevertheless, whatever the cost premium and the payback period may be, the benefits of sustainable buildings are without doubt.

2.3.2. Benefits of Sustainable Office Buildings

Unfortunately most people still rather acknowledge the economic benefit of energy saving costs only (WBCSD, 2007), while neglecting the increasing evidence that sustainable commercial buildings have also benefits in the following areas: economics, marketing, government, employee relations and risk management (Yudelson, 2008). All advantages can be summarised into ten major benefits that come along with green buildings, illustrated in Table 2.1.

Table 2.1: Benefits of sustainable office buildings (Yudelson, 2008)

1.	Energy and water cost savings/ lower operating costs
2.	Increased rent and occupancy
3.	Productivity and health benefits for office occupants
4.	Recruitment and retention of key personnel
5.	Risk mitigation (e.g. economic, financial, market, legal, political)
6.	Increased building valuation
7.	Marketing and public relations
8.	Increase in reputation value for public companies
9.	Possible incentive payments from government and utilities
10.	Access to capital from responsible property investing funds

Sustainable office buildings return higher rents, offer faster letting, secure greater occupancy, and generate higher resale value (Smith, 2006; Lützkendorf, 2007; Yudelson, 2008; Pitt *et al.,* 2009; Keeping, Rawstron, 2010). For instance, occupancy rates are approximately 8% higher in LEED labelled offices than non-labelled ones (RICS, 2010). Green buildings are designed to conserve natural resources and improve human health. Additionally they can deliver a variety of public benefits related to resource conservation, indoor air quality, carbon emissions and air pollution (Pivo, 2008). Moreover sustainable buildings offer greater public relations and marketing benefits, assistance with stakeholder relations and even aiding in recruiting and retaining key employees (Dugard, 2007; Yudelson, 2008). On the occupier side, besides lower operating costs, a significantly increased occupant productivity and well-being represent the main advantages (Dixon *et al.,* 2009). In addition, there is a reduction of risk factors, including marketing, financing and securing political authorization to develop (Yudelson, 2008).

In addition to all these benefits of sustainable commercial buildings, one has to consider the future. Engelhardt (2010) puts forward that as for any other insurance one has to pay a little premium, but without sustainability the buildings will soon be considered to carry certain risks and valued accordingly. Lorenz and Lützkendorf (2011) go along with this by claiming that sustainability is part of any valuation, i.e. also of conventional buildings. The higher risks that are associated with not-sustainable buildings are for instance faster obsolescence and tenant fluctuation which has to be considered and priced accordingly (ibid).

Various stakeholders of the property market became aware of the majority of the benefits of green buildings mentioned above. Therefore the next section aims to explore how investor behaviour has changed due to the increasing importance of sustainability, and how this still transforms the commercial property market continuously.

2.3.3. Investor Behaviour and how it transforms the market

Whilst socially responsible investment products have rapidly become a major investment market in the equities sector, property investors are still struggling to find an effective response (Ellison, Sayce, 2007). In 2011 Hill and Lorenz put forward that there is still a visible underinvestment in sustainable properties. Even, if lack of demand is not a key barrier, occupiers believe that the additional costs of sustainability and undersupply are restricting market growth (Dixon, 2009). The industry talks about the so called 'circle of blame' (Cadman, 2007) shown in Figure 2.2, as the main reason for slow progress in the delivery of sustainable commercial buildings, whereby the four main stakeholder groups in the commercial property sector: investors, developers, occupiers and constructors, blame each other, naming availability and demand of such buildings as the main reasons (Dixon, 2009). This was echoed in 2008 by RICS with asking questions such as: 'How and when does an abundance of interest in sustainability and a strong will to go green translate into sufficient demand for a viable market?' (Robinson, 2008). However, in 2012 Nelson put forward that tenants increasingly seek sustainable office space, indicating a change of behaviour.

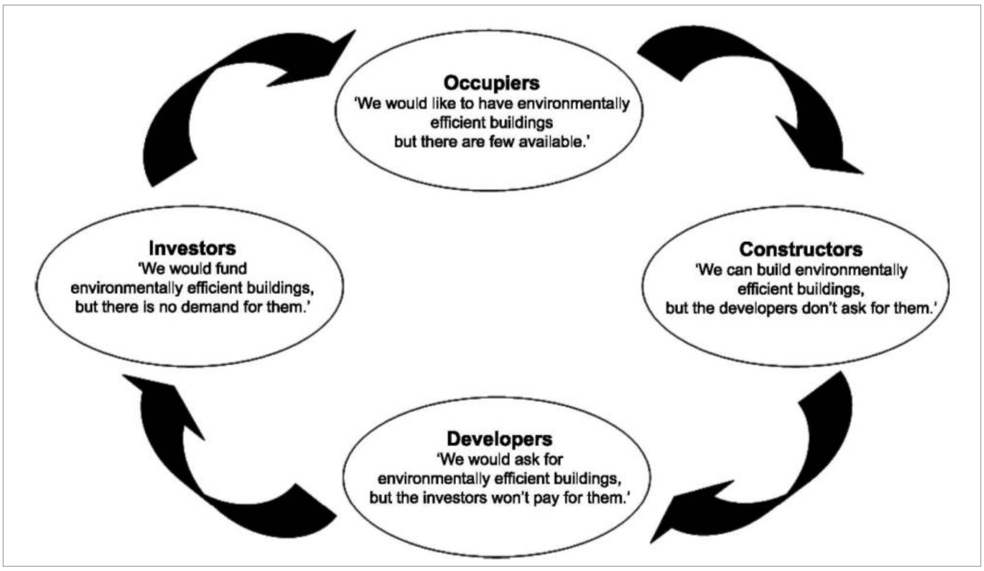

Figure 2.2: The vicious circle of blame (Cadman, 2007)

While the market is slowly shifting towards sustainability, it seems to be clear that 'green' investors can be distinguished from other investors and divided into two main groups: firstly investors intending on capturing outsized returns by being early to capitalize on green investment, and secondly investors more concerned with societal impacts of their investments (Nelson, 2008). For instance European property investors, especially insurance companies, prefer more and more to invest into green buildings as a safer investment product (Katzung, 2011). Moreover companies recognised the benefits of 'going green' in order to highlight their corporate social responsibility (Nelson, 2008), but find at the moment only a limited number of investible assets. Particularly 'blue chip' organisations, with a high public profile, are seeking more sustainable buildings to reflect their strong corporate social responsibility (Ellison, Sayce, 2007). This type of consumer behaviour coming from market leaders will set new future standards (ibid), and thus is a sign that the environmental impact of buildings is becoming important to all players in the property market (Hinnells *et al.,* 2008).

As a result sustainability is fundamentally transforming real estate market dynamics, as the nature of product demanded by tenants, constructed by developers, required by governments and favoured by investors is changing (Nelson, 2008), but also becoming more complex (Meyers, 2008). Nelson declared in 2009 that the recession at that time will only slow, but not fundamentally change the real estate market shifting towards sustainability. Nonetheless greenness will not replace known real-estate attributes such as price, location and conventional amenities (Dixon, 2009). Moreover accessibility of buildings and adaptability within use, seem to still generate higher demand (Ellison, Sayce, 2007). Yet, sustainable features will increasingly enter into tenants' decisions about leasing space, and into buyers' decisions about purchasing properties (Yudelson, 2008; Dixon, 2009). At some point in the future, there will certainly be a tipping point, where green buildings become industry standard for a quality real estate product in developed countries, although it is still unclear when this will be. Nevertheless, owners who fail to adapt quickly to new standards will gradually become less competitive (Smith, 2006), and may find their viability exposed, since older and less efficient conventional buildings are already being devalued, as previously mentioned (Hinnells *et al.,* 2008; Pivo, 2008; Keeping, Rawstron, 2010; Lorenz, Lützkendorf, 2011).

However, having built-up an argument for sustainability and its current importance in the built environment, we have to also acknowledge the barriers towards sustainable construction. Therefore the next section will investigate what kind of problems derive from sustainability for practitioners in the field and how it changes the way they conduct their business.

2.3.4. Barriers towards sustainable construction

Although there are significant drivers to the sustainability market (Dugard, 2007) as previously discussed (e.g. general growing concern about energy prices and climate change, the threat of legislation, the demand of green buildings exceeds supply, and globally, demographic and societal shifts), there are also barriers constraining its growth, such as the length of payback period, initial investment costs and lack of supply (Dixon, 2009). The main barriers to delivering sustainable construction found in literature (Williams, Dair, 2007; Pitt *et al.,* 2009; Kurul *et al.,* 2011; Häkkinen and Belloni, 2011) are summarised in Table 2.2.

Table 2.2: Barriers of sustainable office buildings

1.	Plethora of initiatives and policies
2.	Silo-based structure of the industry
3.	Need to up-skill staff
4.	Affordability
5.	Rules of competition and tendering processes
6.	Lack of client awareness
7.	Lack of client demand
8.	Lack of business case understanding
9.	Lack of proven alternative technologies
10.	Lack of measurement standards

Nelson (2007) states that as every new product, green buildings bring risks along with the rewards. The main risks can be associated with less experienced construction firms through underestimated construction costs, product missing the mark or inability to deliver on promises. Furthermore there are considerable regional variations in the adoption of sustainable construction practices (Nelson, 2008). For that reason the question remains, if the green building delivered is as sustainable as designed. Most sustainability assessment methods still rather measure the design stage (Ding, 2008), while some environmental impacts are better measured by actual performance (Nelson, 2012). There have been several studies comparing the actual performance of sustainable buildings with their intended one, revealing differing results (Hinge *et al.,* 2008; Robinson, 2008). For instance, a New Buildings Institute study in 2008 compared intended energy efficiency with actual energy performance of LEED certified projects, and revealed that the results differed widely from the design intentions. This proves a need for linking sustainable design intent to operational performance (Robinson, 2008) and investigating the barriers preventing this. The UK government acknowledged the performance gap and partially funded a seven year research project on post occupancy in 1995, called Probe (Cohen *et al.,* 2008). Another more current project is the Carbon Buzz, where designers can report the predicted and actual performance of buildings (Stevenson, Bordass, 2011). Furthermore the Usable Buildings Trust aims to better connect client, design and building teams, to help them to be more focused on the built result (ibid). Hinge *et al.* (2008) suspect that the cause of the performance gap is mainly to be found in the user behaviour, neglecting the role of the construction phase. Bordass *et al*. (2004) argue that there are many potential reasons for the performance gap that can be divided into four main categories, i.e. slippage during initial estimation, during design development, during construction and commissioning, and once completed. This study concentrates on the construction stage, in order to explore how knowledge on building sustainably is transferred between professionals and operatives, due to the significance of this transfer in the delivery of sustainable buildings.

Katzung (2011) states that another problem for investors at the moment is still a lack of defining sustainability, respective lack of criteria. Although many countries put new policies regarding sustainable buildings in place, sustainable building certificates have already established certain sustainability standards and thus offer a possibility to compare sustainability levels of different buildings on a voluntary basis. Wallbank and Price (2007) state that the introduction of such rating tools has brought a change in the way buildings are designed and operated, and has raised awareness for sustainability across the whole sector. So far rating tools have largely been used as mechanisms to increase the commercial potential of one property when compared to another, all other factors being equal (Wallbank, Price, 2007). Due to the increasing importance of sustainable building certificates and because they were used in this study as the definition for a sustainable office building, the next section will explore these further.

2.4. Sustainable Building Certificates

Since there is an increasing need for all industries to respond to the sustainability agenda, one of construction industry’s responses is the development of rating methodologies for assessing the sustainable performance of buildings (Atkinson, Yates and Wyatt, 2009). Many countries worldwide have developed systems for evaluating building performance (see Figure 2.3) against a wide range of criteria, and awarding certificates such as BREEAM (BRE Environmental Assessment Method) in the UK or LEED (Leadership in Energy and Environmental Design) mainly in the USA. Such eco-labelling has been one of the most important mechanisms used to encourage market participants in the real estate sector to voluntarily improve the environmental performance of their commercial building stock (Lützkendorf, 2007; RICS, 2010; Häkkinen, Belloni, 2011).

Figure 2.3: World map with locations of sustainable building rating systems (Lange, 2012)

The demand of green building rating systems increased in the past few years, especially in those countries that are not able to develop their own rating system, because of for instance their size or academic infrastructure (Gertis *et al.,* 2008). Therefore one important aspect of rating systems is that they are easily adaptable to other climate, cultural or economic regions (Ding, 2008). However, the plethora of sustainable building certificates worldwide and their definitions also caused confusion within the different stakeholder groups (Lützkendorf, 2007; Häkkinen, Belloni, 2011). As a result various attempts have been made to combine the certificates into a major one. For instance the European Community's Seventh Framework Programme funded a research project on this matter in 2010 called Open House. The project is currently (2013) still on-going.

2.4.1. The Focus of this Study on Germany and the UK

This study compares practices of construction teams delivering new office buildings to sustainable building standards in Germany and the UK. There are two main reasons for the selection of these two countries. Firstly, both countries have a large and comparable expected construction volume of new sustainable buildings, as pointed out in Figure 2.4 (Nelson, 2008). This figure also shows that both countries are aiming for the same high level of sustainability. Secondly, both countries are very strong regarding the implementation of sustainability principles.

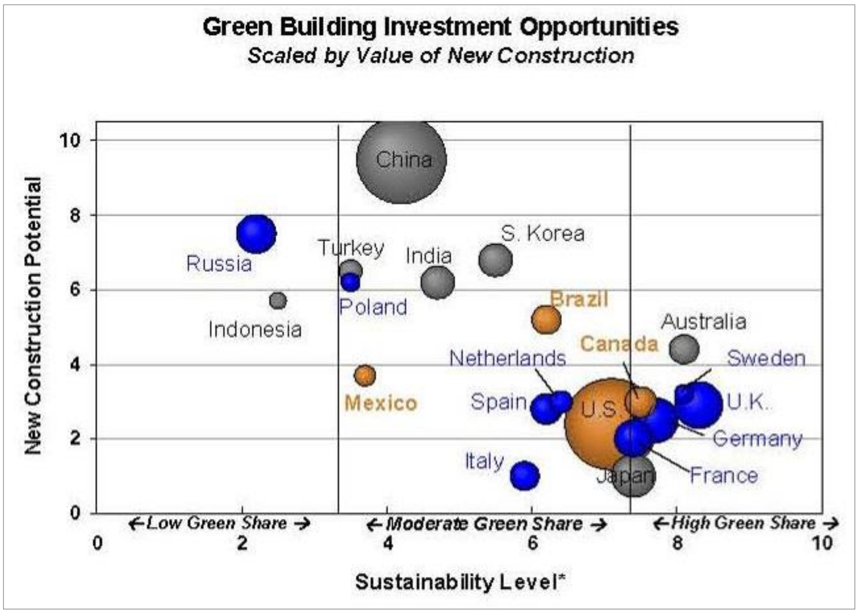

Figure 2.4: New construction Potential (RREEF, 2008)

The UK strengthened its legal framework through the publication of the Energy Act 2008, the Climate Change Act 2008, and most importantly the Carbon Reduction Commitment which started in April 2010. The main implications of this are that new constructions have to be built zero-carbon in the future. Though, as previously mentioned, the Coalition weakened this policy regarding home appliances in residential buildings (Porritt, 2011).

In the German context, the first Energy Savings Act was already in force in 1976, with requirements regarding thermal insulation of buildings, efficiency and energetic maintenance of appliances for heating, ventilation and hot water, as well as others. Further enhancements were made over the years, leading into the Energy Saving Ordinance (ENEV - Energieeinsparverordnung) in 2002 (EPBD, 2008). The ENEV was last updated in 2009 and a new version is planned for 2014. Furthermore voluntary measures have been in place for years in Germany, since energy prices are much higher compared to other countries and actually have doubled between 1998 and 2008 (Hegner, 2008). Many investors already accepted that higher upfront costs lead to long-term lower operating charges (Kauntze, 2007). Moreover Germany is actively pursuing green technology as the next economic model (Dugard, 2007), and is also home of the first world's ecological office tower, the 'Commerzbank' in Frankfurt am Main.

Although the existing building stock in Europe and America is approximately over eight times larger than the new development sector (Smith, 2006), this research examines new construction. This is due to the higher comparability of new constructions in regards to their sustainability compared to refurbishments. Moreover it was decided that the level of sustainability is more comparable by focusing on construction projects aiming for sustainability certificates. The German sustainability certificate, DGNB had a well-developed certificate for new office constructions in place when this research project started, while the ones for refurbishments were still in a developing stage. This is quite common as all rating systems first develop certificates for new construction, before ones for the existing building stock (RICS, 2012). This led to more certificates being awarded for new buildings so far than for existing ones in Europe (ibid). Therefore the decision was made to focus this research on new office constructions aiming for sustainability certificates. Furthermore, it can be assumed that the results of this study can be adapted and applied to refurbishments and other building types as well.

2.4.2. BREEAM - UK's Sustainable Building Certificate

BREEAM was the first environmental assessment method worldwide, initiated in 1990 as a voluntary tool for new commercial buildings (Schweber, 2013). Dixon, Colantonio and Shiers (2008) assert that BREEAM and the Environmental Impact Assessment (EIA) are the most commonly used tools in Europe. In 2005 BREEAM won the award for 'the worldwide best program for environmental assessment' at the World Sustainable Building Conference in Tokyo. Nonetheless, only about 7% of newly build offices in the UK are rated BREEAM 'good' or above annually (Dixon, 2009). Schweber (2013) goes along with this by stating that especially BREEAM for commercial new build is the best established certificate regarding uptake and recognition. Keeping and Rawstron (2010) found out that a high BREEAM rating is nowadays an important criterion for commercial property investors in the UK. Although it started as a voluntary tool, BREEAM is more and more required as a condition for planning permissions and as a tender requirement for publicly funded non-residential projects (Schweber, 2013). BREEAM was also adopted as a 'mandatory mechanism' for all UK government procurement in 2000 (ibid).

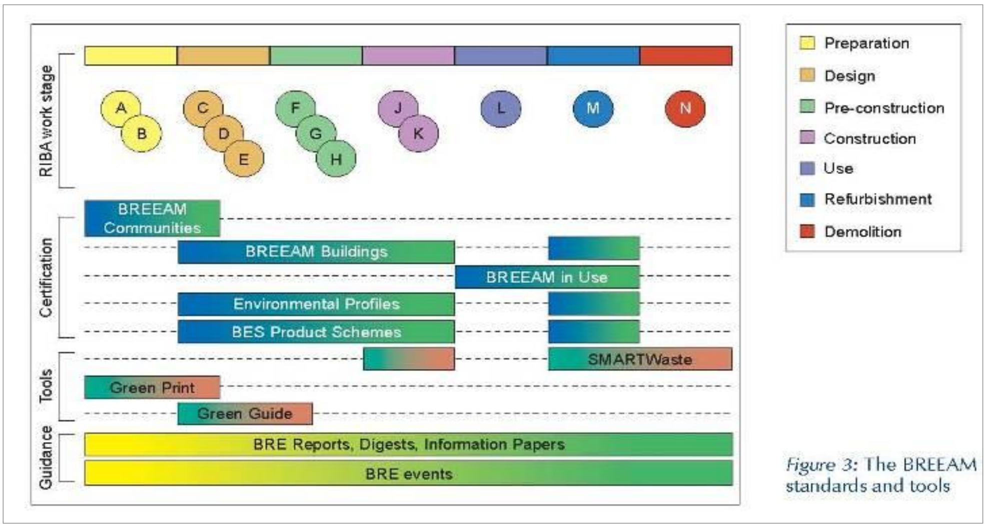

Figure 2.5: The different BREEAM standards (Atkinson, Yates and Wyatt, 2009)

Currently there are 16 different BREEAM certificates available for all kinds of buildings, such as residential, commercial, industrial or schools (Schweber, 2013). Furthermore, there are several different BREEAM standards relevant for different RIBA work stages, as shown in the top row of Figure 2.5. The second row presents the different certificates. The BRE (Building Research Establishment) offers tools and guidance throughout the whole process, to be seen in the two lower rows of Figure 2.5.

Illustration taken out due to copyright reasons

Figure 2.6: BREEAM scoring for non-domestic buildings (Saunders, 2008)

Figure 2.6 illustrates the BREEAM scores for non-domestic buildings in detail. The project can gain a certain number of assessments credits in eight different categories: management, health and wellbeing, energy, transport, water, materials, land use and ecology, and pollution. Each category has various items that are assigned to a certain number of credits (Schweber, 2013). The overall number of credits will then result in one of the five BREEAM ratings: pass, good, very good and excellent and outstanding. If the assessment score is below 10% the building fails in achieving the certificate. Nonetheless, Schweber (2013) criticizes that there are multiple ways of obtaining the credits, especially for a lower rating. In contrast to other certificates this results in tensions as many BREEAM criteria are anyway similar to standards requested by building codes, planning requirements and client demands (ibid).

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Figure 2.7: BREEAM certification process (Saunders, 2008)

Figure 2.7 describes the certification process for non-domestic buildings, including the corporation with an assessor. The result of step three ‘information collection’ represents the quality of the certificate. Thus, for instance, if the information is only on the design process, the certificate does not value the built result, i.e. how sustainability is put into practice. The BRE reacted on this deficiency with the development of a new BREEAM certificate in 2011, with many changes regarding the assessment process, the most important one being performance measurements of the building in use for up to three years after completion. The BREEAM in-use certificate is supposed to improve the environmental performance of existing non-domestic buildings, i.e. currently offices are predominant (BRE, 2013). The information collected for the assessment is divided into three sections: first the asset, secondly the building management and thirdly the occupier.

Furthermore the data required is split across nine different categories: energy, greenhouse gas emissions, water, waste, air quality, noise, lighting, health and wellbeing (ibid). These categories are different to the other BREEAM certificates, as e.g. transport is not included anymore. Moreover BRE (2013) describes the auditor's role (note the change in terms, i.e. before it was the assessor) as to only verify and validate the information provided and request the final certificate. Thus this change can be seen as an improvement of the BREEAM certificate, but it still differs widely from the German certificate which will be discussed next.

2.4.3. DGNB - Germany's Sustainable Building Certificate

Germany started its green building rating system, DGNB (Deutsches Gütesiegel für Nachhaltiges Bauen) only in 2008. The timing of its introduction should be considered against its strong and relatively long-standing legal history regarding energy efficiency and sustainability, as presented in section 2.4.1.

The German green building rating system is based on six goods: natural environment, natural resources, health, economic, social and cultural values. The aim of protecting these goods is the main aim of the rating system, and therefore the five main criteria groups, ecological, economic, social and technical quality and quality of the process, were developed out of them (Gertis *et al.,* 2008; Graubner, Lützkendorf, 2008). The sixth main criterion, quality of location, is regarded as separate, as it is given in each construction project.

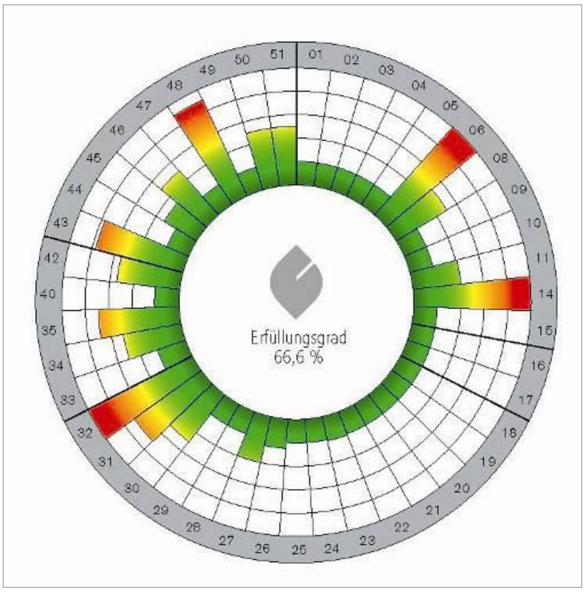


Figure 2.8: DGNB certificate display (DGNB, 2008)

The 51 single criteria of the five main criteria are displayed in the outer ring of Figure 2.8. Such criteria are for instance ozone depletion potential, risks to local environment, sustainable use of resources, microclimate, total primary energy demand and share of renewable primary energy, waste by category, building lifecycle costs, and suitability for conversions. Each ray of the inner ring displays one single criteria and its value in the assessment, i.e. the shorter the ray, the better the mark (Gertis *et al.,* 2008). Hence the short rays are green, turning into yellow, orange and finally red as they extend, adopting the concept of a traffic light. Three major values have been defined for each criterion. The lower limit indicating the minimum value the building has to achieve in that criterion in order to get the certificate; the mean value representing the average value in this regards and the target value as the highest possible value to achieve sustainability in this criterion (Graubner, Lützkendorf, 2008). In the centre of the circle the overall result is displayed, as a number in percentage, resembling the grade of fulfilment of all possible sustainability aspects, and a leaf in the colour of the achieved certificate. The key to this can be seen in Figure 2.9. Gold can be achieved with 80-100%, silver with 65-79% and bronze with 50-64%. All buildings below 50% of fulfilment fail in achieving the certificate.

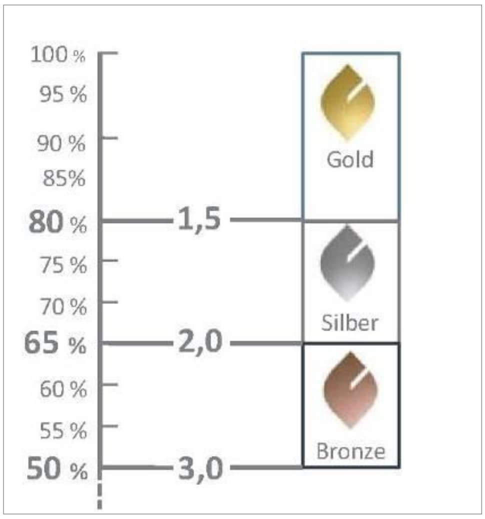


Figure 2.9: The three levels of DGNB (DGNB, 2008)

Figure 2.10 describes the certification process. As shown in step 3, DGNB uses a pre-certificate, which can be very useful for the owner in terms of marketing aspects in order to attract investors and future tenants. BREEAM has a similar one called interim certificate. The DGNB certification includes a check-up on the construction process, and later on the quality of the built result. This is supposed to link the design intent with the operational performance of the green building and might be due to an increasing awareness towards the performance gap between design intent and built result. As stated previously the BRE had only reacted to this deficiency in 2011 by introducing performance measurements of buildings in use as previously presented. In the long run this will enable the practitioners to control the sustainability performance of the built result and hence clarify, whether the problem of the performance gap decreases over time.

Figure 2.10: DGNB certification process (DGNB, 2008)

Table 2.3 summarises the comparison of the main aspects of the two certificates. Since DGNB was launched 18 years after BREEAM, its update process is at the moment still on-going. This mainly refers to the development of different certificates for different building types (Graubner, Lützkendorf, 2008). The certificate started with office buildings and then continued to develop certificates for other buildings, such as residential in 2010.

The main differences between these two certificates are in the weightings. DGNB developed six main criteria groups (natural environment, natural resources, health, and economic, social and cultural values) according to common definitions of sustainability itself. Whereas BREEAM developed eight categories (management, health and well-being, energy, transport, water, materials, land use and ecology and pollution) being more focused on the built environment. Another difference lays in the way the auditor, respective assessor, is integrated into the whole project. The auditor (DGNB) / assessor (BREEAM) is a specialist trained by the organisation (BRE or DGNB) and accompanies the entire process from the planning stage onwards. He/she plays an important role in the certification process. Additionally the DGNB auditor is supposed to coordinate all involved parties, offers support on sustainability related questions and helps to avoid conflicts between them (Jaeger, Hunziger, 2009). This suggests that the auditor actively assists the project manager. This aspect was further explored during fieldwork and is discussed in detail in Chapters 6 and 7.

Table 2.3: Comparison BREEAM – DGNB
(Atkinson, Yates and Wyatt, 2009; DGNB, 2008)

	BREEAM	**DGNB**
Launch Date	1990	2008
Ratings	Pass, Good, very good, excellent, outstanding	Bronze, Silver, Gold
Weightings	Applied to each issue category	All credits equally weight, although one of the main criteria, quality of location, is regarded separately.
Information gathering	Design/ management team or assessor	Design team and auditor together
Assessment	Trained assessors	Trained auditors
Certification labelling/ Third party validation	BRE	DGNB
Update process	Annual	Constantly
Governance	UK Accreditation Service	DGNB (Deutsche Gesellschaft für nachhaltiges Bauen)
Required qualification	Competent persons scheme	Training scheme and exam

This section presented the two sustainability building certificates BREEAM and DGNB as a voluntary possibility to rate the sustainability of buildings. In addition to this, they might also offer a way to better control the performance of buildings during the whole life cycle of a building and hence support closing the performance gap between design intent and built result, as stated earlier. This approach is introduced in the following section.

2.4.4. Sustainable Building Certificates and the Project Knowledge Value Chain

Wallbank and Price (2007) point out that sustainability certificates could provide a framework for developing a so-called ‘project knowledge value chain’, in which the knowledge on design, construction, performance and operation of a building can be continuously developed, captured, transferred and managed. As illustrated in Figure 2.11, the focus is on transferring knowledge from one stage of a building's life cycle to the next. Since this approach uses the concept of a buildings life-cycle, it is easier understood by all project participants. It is further argued that there is a requirement to transfer relevant information in each of the rating processes in order to prevent a knowledge loss in-between the different project phases (ibid). As stated in section 2.3.4, the performance gap between sustainable design intent and built result is widely acknowledged (Bordass, Leaman, 2013). Hence it is vital to further investigate whether a successful transfer of knowledge on how to build sustainably could offer one possibility to bridge this gap. This study focuses on the construction process, as the link between the design stage and the actual use of the building. It can be argued that if the built result is as sustainable as the design intended, the user has a higher chance to operate the building sustainably.

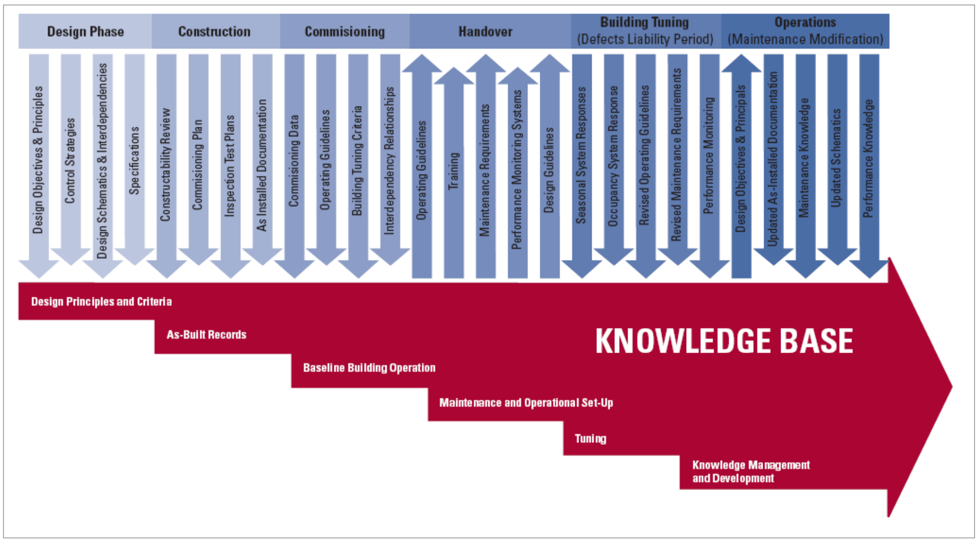


Figure 2.11: Knowledge Transfer as part of a rating framework (Wallbank and Price, 2007)

Overall there is still a deficit of understanding how knowledge on building sustainably can be transferred and widely adopted between professionals and operatives during construction, despite the significance of this transfer in the delivery of sustainable buildings. This could be the reason for green buildings that are not performing in a sustainable way, although they are assumed to do so. Hence these buildings represent an unproductive investment, and moreover do not support achieving governmental targets, such as cutting down carbon emissions in the long run. Therefore the next section will further explore what kind of expert knowledge is needed for the successful delivery of sustainable buildings, and how it can be shared more efficiently between all project participants.

2.5. Knowledge on how to build sustainably

2.5.1. Knowledge and awareness of construction industry's workforce

One of the questions to begin with is, does each stakeholder group involved in a sustainable construction project possess the knowledge on how to build sustainably? Moreover do they put this knowledge into practice accordingly? There are many factors influencing the consideration of sustainable aspects for various professionals in the field of different countries, which are depicted in Figure 2.12, as an outcome of a World Business Council of Sustainable Development (WBCSD) study in 2009, revealing an actual lack of knowledge within practitioners in the field. This is supported by others, e.g. Rodrigues *et al.* (2012) who put forward that the UK market is currently still lacking skilled professionals and Thomson *et al*. (2010) who claim that there is a lack of understanding the sustainability concept among practitioners.

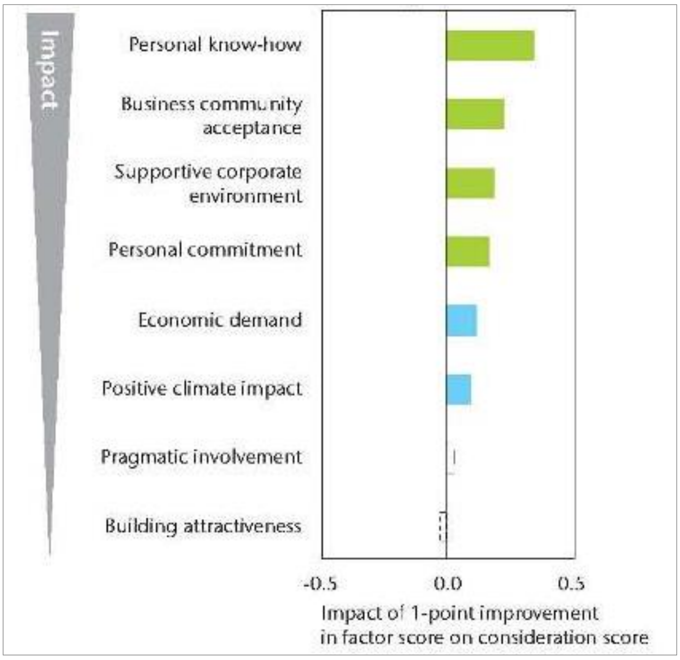


Figure 2.12: Factors influencing consideration of sustainable practices (WBCSD, 2008)

Moreover the WBCSD (2008) investigated the awareness and following involvement of building professionals in various countries. The results are summarised in Figure 2.13. The example of Germany shows the best result in this study. Nonetheless, even though 98% were aware of sustainable buildings, only 45% of them have been actually involved with it.

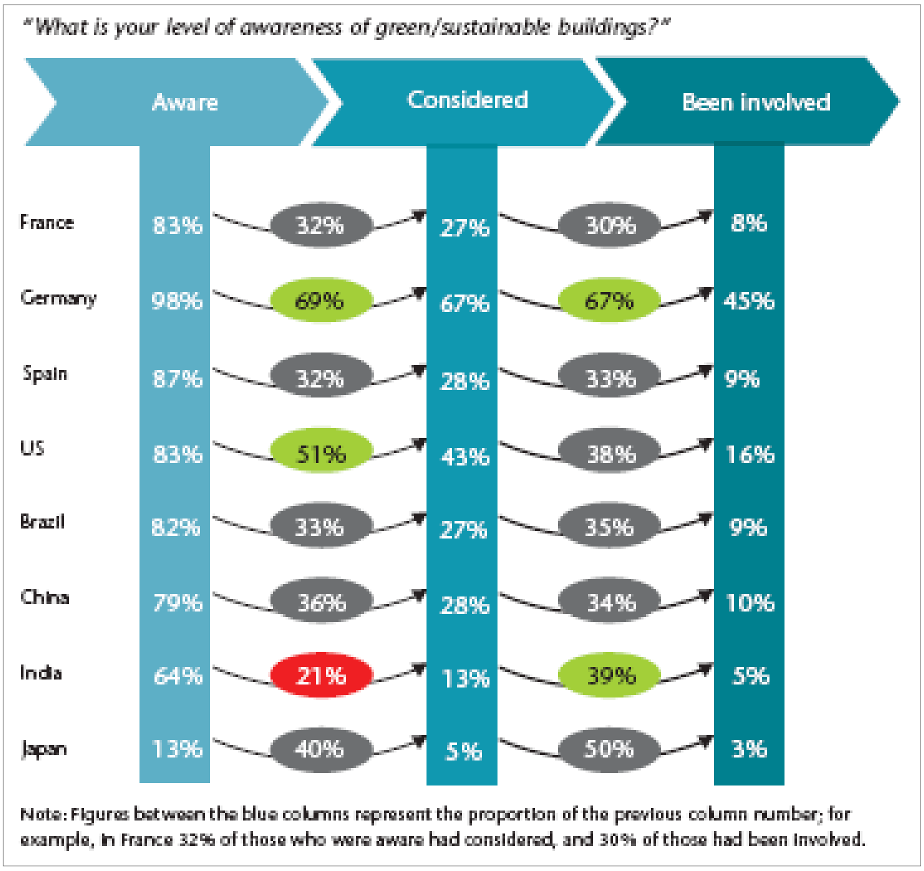


Figure 2.13: Awareness and involvement of building professionals (WBCSD, 2008)

These figures might be unexpected and disturbing, but also lead to the question, whether this lack of specialised knowledge is the reason for underperforming sustainable buildings. Moreover does the knowledge and awareness towards sustainable construction maybe only exist in certain professions, i.e. professionals or construction workforce? As a result the next section will investigate the differing education and training background of construction industry's workforce in Germany and the UK.

2.5.2. Apprenticeships, skills and training of construction industry's workforce

Construction industry's workforce can be divided into two main groups, according to their training background and job roles, i.e. operatives and professionals. While most professionals in the field acquire a university education in order to perform their jobs in Germany and the UK, the educational background of operatives varies widely. As a result this section focuses on job training of operatives.

Even, if most operatives complete some kind of apprenticeship, their knowledge and skills vary depending on the country they were trained in. Steedman (2011) puts forward that UK's apprenticeships differ widely from most continental European ones and mostly not for the better. This view is supported by Dixon, Colantonio and Shiers (2008) who argue a lack of training and education in the UK construction industry. Table 2.4 depicts various differences in apprenticeships in the two countries of focus.

Table 2.4: Comparison of English apprenticeship with other European models Steedman (2011)

Apprenticeship – England	Apprenticeship –Germany,
Employed status	Trainee status
Wage (high relative to other countries)	Trainee allowance
Short duration (average one year)	Long duration (average three years)
Most at lower skill level (Level 2)	Most at higher skill level (Level 3)
Outside providers train	Employers train on-the-job
Only 60% of apprentices are under 25	Apprentices are normally under 25
Minimum 100 hours off-the-job training	Minimum 900 hours off-the-job training
4-8% of employers train apprentices	25-30% of employers train apprentices

As indicated in Table 2.4, apprentices in England are paid more and their status is higher than in Germany. Thus they are not in high demand by employers and mostly funded by government initiatives (Steedman, 2011). Moreover differences include the duration of the programme, as apprenticeships are only one year in the UK compared to three years in Germany. Additionally the off-the-job training is on average nine times higher in Germany. As a result this leads to a lower skill level of English apprentices in general (ibid). These differences might overall lead to the assumption that the training, skills and awareness regarding sustainable construction is higher with German operatives than with English ones. This issue was taken into account and further investigated during fieldwork. The results are presented in Chapters 6 and 7.

2.5.3. How to overcome the knowledge gap

Despite the proximity of the legal targets coming into force still only a small number of professionals in the industry possess 'the specialised knowledge and experience to design and operate sustainable buildings successfully' as stated before (Nelson, 2007; Kurul *et al.*, 2011). While there is a difference between practical, experienced-based and theoretical knowledge (Nahapiet, Ghoshal, 1990), problems could evolve in how to put the new building techniques into practice. Rohrbacher (2001) argues that although nowadays almost all actors involved in the construction process claim to strive for sustainability, this discourse is not yet put into practice accordingly. The way sustainability is perceived and translated into practice varies widely between actor groups (Rohrbacher, 2001). Wallbank and Price (2007) support this view by affirming this 'knowledge gap', where critical knowledge of building design and operation is lost in between different stages of the construction process, and later on during the building life cycle. This was also proven for instance in a New Buildings Institute's study (2008) that compared intended energy efficiency with actual energy performance of LEED certified projects, revealing that the results differed widely from the intentions. This shows a clear need for linking design intent to operational performance (Robinson, 2008). Previous research has shown that for professionals the main barriers to adopt sustainable building techniques are personal know-how and commitment (WBCSD, 2008). This reflects not only a lack of training and education in relevant techniques (Dixon, Colantonio, Shiers 2008), but also personal commitment and a supportive environment and business acceptance (see Figure 2.12 in section 2.5.1).

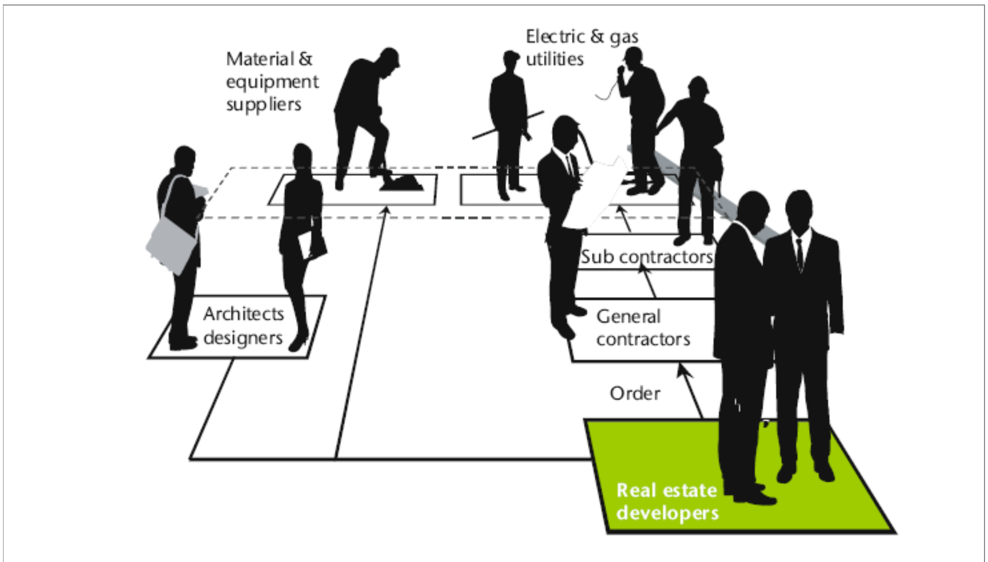


Figure 2.14: Procurement hierarchy for office building development (WBCSD, 2009)

Regarding the office property market, the complexity of this sector increases this challenge. Figure 2.14 shows the diverse stakeholders and their relationships in the process of an office construction. Each and every single market player is required to possess the knowledge on sustainable buildings in his/her area of expertise and should also broadly understand the areas of expertise of the other participants. Therefore it is vital to understand how a better knowledge flow between various sustainable construction project participants can be enhanced.

Although all project team members have to constantly absorb new technology and techniques in order to remain competitive (Fong, 2003), Dixon, Colantonio and Shiers (2008) discovered that sustainability engagement is higher for senior staff and in larger organisations. However, so far not much attention has been given to operatives, who are largely responsible for the delivery of the building. Hereby Ugwu (2005) stresses the translation of strategic policy initiatives to concrete design guidelines and actions at the micro level. This requires top down and bottom up approaches in analysing current practices in designing for sustainability, and how construction companies connect, deploy and manage this sustainability knowledge (Ugwu, 2005). As a result this study involves both groups as research participants to further explore where different types of knowledge reside, where the knowledge loss occurs and moreover to identify the different knowledge needs of the various participants.

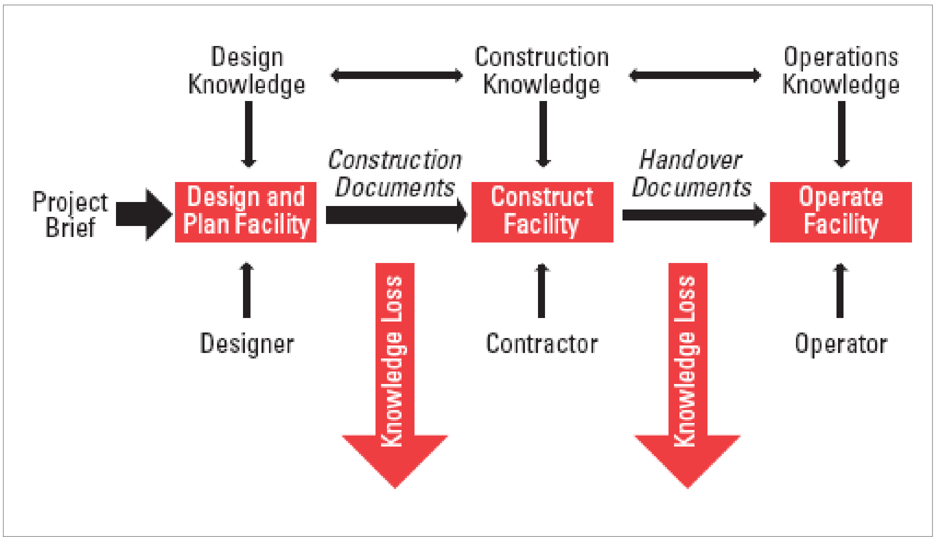


Figure 2.15: The knowledge cycle – pre-rating (Wallbank and Price, 2007)

Figure 2.15 shows that some knowledge is lost in each project phase. One of the main reasons for this could be a missing link between the phases or between the diverse project participants of each stage regarding the ‘total ownership’ of the built result. While good design may establish sustainability potential, good performance can only be achieved when all the operational issues are fully implemented (Wallbank, Price, 2007). This ‘knowledge gap’ is also known as the ‘credibility gap’, where the design intent is not fully informed by construction and vice versa resulting in a ‘performance gap’ as previously argued (Bordass *et al.,* 2004).

The WBCSD (2008) goes along with this, by suggesting a more holistic design approach, where shared responsibility and interdependence among the various participants is encouraged. It is seen as especially important to include construction companies already during the design stage, due to their important role in putting the design intent into practice (Häkkinen and Belloni, 2011). This approach is also known as the so-called 'integrative planning process', i.e. involving various professionals and energy experts from an early stage on. This early cooperation of all project participants can avoid expensive revisions and disruptions later on in the construction process (WBCSD, 2009). Moreover Ding (2008) argues that environmental issues and environmental assessment tools should already be introduced to a project as early as the appraisal stage.

Kamara *et al.* (2002) put forward that the application of general knowledge management strategies to architecture, engineering and construction industry should 'reflect the context of this industry with respect to the way it conducts its business and the types of knowledge, which are critical for its success.' As sustainability issues are changing the definition of tasks within the sector (Kamara *et al.,* 2002; Häkkinen and Belloni, 2011) difficulties might emerge because of fast technical changes (Cohen and Levinthal, 1990). Therefore knowledge management strategies might require adjustments. As Häkkinen and Belloni (2011) put forward, sustainable construction 'is not hindered by a lack of existing information, technologies and assessment methods, but because it is difficult to adopt new processes and working methods in order to apply new technologies.'

There is considerable research on the certificates themselves (e.g. Atkinson, Yates and Wyatt, 2009; Saunders, 2008; Schweber, 2013) and the technological solutions, which help to achieve the required performance levels (e.g. Halliday, 2008). However, not much attention is paid to the actual people involved (Schweber, 2013). There is still a lack of understanding on how knowledge can be transferred and widely adopted between professionals and operatives, and in between the different project stages. The increased diversity of actors with different knowledge repositories, resources and capabilities, as well as the capacity to access and share this specialised knowledge, appears to be one of the key issues hereby (Alguezaui, Filieri, 2010; Häkkinen, Belloni, 2011). Therefore the next chapter explores possibilities to enhance KT further.

2.6. Conclusion

This chapter has reviewed and critically discussed the literature on sustainability within the built environment, and presented related issues such as cost premium, payback periods, benefits, and barriers, market and investor behaviour.

Furthermore the reasoning for choosing Germany and the UK as the focus of the study was put forward, as they have a comparable high sustainable construction volume and high standards in implementing sustainability principles. It then moved on towards presenting sustainable building certificates as a voluntary possibility to rate and compare such buildings, focusing especially on BREEAM and DGNB, as UK's and Germany's certificates.

In the last section of this chapter lack of knowledge and awareness of practitioners in the field was revealed as one of the main barriers towards sustainable construction. The emerging need for high quality performing sustainable buildings seems to be in contrast with more and more evidence on built results failing the design intent (Bordass, Leaman, 2013). Capturing and transferring knowledge from one stage of a building's lifecycle to the next is already difficult and with a considerable knowledge loss occurring during this process (Wallbank, Price, 2007). Additionally sustainability issues render this even more challenging, as they change the required knowledge and introduce new knowledge. Therefore the next chapter will provide an overview of the area of knowledge and investigate how to define contents and types of knowledge on sustainable construction needed by the practitioners in the field. Moreover it further explores how knowledge transfer between the various practitioners can be enhanced in order to overcome the performance gap.

CHAPTER 3

AN OVERVIEW OF THE AREA OF KNOWLEDGE

3.1. Introduction

Chapter 2 presented the context of this study regarding sustainability in the built environment and how construction industry is adapting to it. The benefits as well as the barriers were discussed. The performance gap between sustainable design intent and built result was identified as one of the main barriers to overcome. A general lack of knowledge and awareness towards sustainable construction of practitioners was identified as a possible reason for under-performing sustainable buildings. It can be assumed that a better management and sharing of knowledge in construction projects could help to solve this problem. As a result the aim of this chapter is to critically discuss the theories of knowledge, knowledge management and especially knowledge transfer in terms of how they can be applied to sustainable construction in order to overcome the performance gap.

This chapter is divided into three major parts. The first section defines the subject areas that have emerged through sustainability issues in the built environment and allocates knowledge types to them. The chapter then moves on to the area of knowledge management in general. This is followed by examining the meaning of KM within the context of the built environment and especially for knowledge on how to build sustainably. Various key concepts are discussed in regards of their relevance and potential to be applied to this issue, in line with the first research objective presented in Chapter 1. It is believed that an enhanced knowledge transfer between all project participants can help to overcome the performance gap. Therefore the third section explores the area of knowledge transfer (KT) in detail and defines vital components and preconditions of KT. The chapter concludes by presenting general influencing factors of KT, in line with the second research objective.

3.2. Knowledge Types

A distinction of knowledge types is important, when discussing knowledge in construction project teams dealing with sustainability issues. It has already been established in Chapter 2 that one of the main difficulties in achieving a well performing sustainable building lies in the construction stage, i.e. putting the design intent into practice (Bordass *et al.,* 2004; Robinson, 2008). A reason for this could be the lack of knowledge and awareness of construction industry's workforce

(WBCSD, 2009). Therefore it is vital to define the kind and type of new knowledge that is introduced to construction industry through sustainability in order to provide a more purposeful research approach to the issue.

There are two types of knowledge, tacit and explicit, that are widely accepted, often referred to, and first identified by Polanyi (1967; in Nahapiet, Ghoshal, 1998). Explicit knowledge describes the type of knowledge that is formal and systematic (Nonaka, 2000). It is easily expressed or codified and can be described as an accessible asset (Lu, Sexton, 2007). Hence information can be seen as a form of explicit knowledge and should not be confused with it. Previous research (Kurul *et al.,* 2007) has shown that knowledge and information are often falsely considered to be the same.

Tacit knowledge is rather personal and context dependent, and therefore very difficult to express and transfer (Fernie *et al.,* 2003). It can generally be understood as the form of knowledge that exists within an individual and is intuitive (Haldin-Herrgard, 2000). The creation and use of tacit knowledge is dynamic, human centred and specific to a particular time and context (Lu, Sexton, 2007; Sun, Scott, 2005). Since tacit knowledge is unarticulated knowledge, it is often a precondition for explicit knowledge (Fong, 2003), and thus difficult to exploit organisationally, even if clearly articulated (Bresnen *et al.,* 2003). As a result some knowledge will probably always remain tacit. Yet, McKinlay (2000; in Fernie *et al.,* 2003) notes that tacit knowledge is the real currency of the informal economy of the workplace.

Nevertheless, research on knowledge moved on since Polanyi's distinction of 1967 into tacit and explicit. Yet, the subsequent concepts can be described as an advancement of the original construct as they possess certain similarities. Borgatti and Cross (2003) for instance formulated a distinction of knowledge: declarative (know-what) and procedural (know-how). Nahapiet and Ghoshal (1998) divide knowledge into three main kinds: practical experience-based knowledge, the theoretical knowledge derived from reflection, and abstraction from that experience. Hence practical and experience-based knowledge are similar to tacit knowledge, while theoretical knowledge can be described as another form of explicit knowledge. Furthermore De Long and Fahey (2000; in Lu, Sexton, 2007) distinguished between three types of knowledge, i.e. tacit, explicit and relationship/ social knowledge. The latter is described as further developed tacit knowledge that results out of collaborative work. This concept is especially interesting in the context of this research, i.e. approaching KT from a social network perspective.

When applying these theoretical concepts to the area of sustainable construction it is vital to first identify the actual subject areas. It has been argued that sustainable construction projects are more complex than conventional ones due to a modified technical knowledge (Häkkinen, Belloni, 2011) on new technologies, new building materials and the techniques required to install them. Thomson *et al.* (2010) classified the implicit knowledge held by a sustainability advisor, which is summarized in Table 3.1.

Table 3.1: Classification of knowledge held by the sustainability advisor (Thomson *et al.*, 2010)

Expert knowledge of	Sustainability tools Delivering sustainability Sustainability concept and assessment
Tacit sustainability knowledge	Past experience of sustainability concept and assessment Past experience of sustainability tools Acquired sustainability related knowledge gained through professional practice regarding the life cycle of a building
Tacit knowledge	Acquired knowledge gained through professional practice regarding the life cycle of a building

As a result three subject areas of this new knowledge on how to build sustainably can be defined as follows:

- New sustainable materials
- New technologies
- New building techniques

The previously discussed knowledge types have to be allocated to these three subject areas in order to fully understand the whole knowledge process. This research followed on the one hand Borgatti and Cross (2003), and on the other hand the original concept of Polyani (1967; in Nahapiet, Ghoshal, 1998). The information on the use and performance of the materials can be stored and accessed in e.g. manuals. Hence it can be argued that the knowledge on new sustainable building materials resembles mostly a ‘know-what’ in terms of explicit knowledge. New technologies, such as solar panels or rainwater harvesting systems, require a combination of ‘know-what’ and ‘know-how’, as explicit and tacit knowledge, due to their more complex nature. Whereas new building techniques require mostly tacit knowledge, in terms of ‘know-how’ for the correct installation of new materials and technologies, or conventional materials in a new way. The importance of ‘know-how’ in the context of sustainable construction is also emphasized by Thomson *et al.* (2010). An example could be e.g. drawings on construction details, which are coded knowledge and thus explicit, though require tacit knowledge in form of ‘know-how’, i.e. skills of craftsmen, for their correct installation. As a result various combinations of the subject areas and hence knowledge types are expected to be found in practice. The findings on this issue will be discussed in Chapters 6 and 7.

Regardless of the knowledge type definition used, the management of knowledge became an important aspect in business performance. In order to understand how knowledge is best managed and shared in a sustainable construction project, and moreover in line with the first research objective presented in Chapter 1, the following section will explore the concept of knowledge management.

3.3. Knowledge Management

Interest in knowledge management (KM) has steadily increased since the 1990s (e.g. Nahapiet, Ghoshal, 1998; Ives, 1998; Depres, Chauvel, 2002). Depres and Chauvel (1999) examined the number of published KM articles between 1988 and 1998, and discovered a hundredfold increase, from three in 1988 to 320 in 1998, with a continued popularity.

Generally KM can be described as an enhancement of business performance through an improvement of knowledge diffusion (Kamara *et al.,* 2002). Therefore it became more and more important in the field of business management, as it is very business orientated and focused on outcomes (Depres and Chauvel, 2002). Snowden (1999; in Kamara *et al.,* 2002) describes KM as 'the organizational optimization of knowledge to achieve enhanced performance, increased value, competitive advantage and return on investment, through the use of various tools, processes, methods and techniques.' It is important within this process that the different types of knowledge, e.g. explicit and tacit, are acknowledged and managed in order to meet existing and emerging needs (Egbu, 2004). KM activities, such as searching and sharing knowledge are critical for a company's continuous innovation, and consequently to satisfy expectations and needs of their various clients (Alguezaui and Filieri, 2010). In summary it can be argued that KM is a widely accepted factor of success for organizations dealing with complex tasks (Wilkesmann *et al.,* 2009).

For organisations, knowledge resembles a component of their task-performing system (Kamara *et al.,* 2002). There are two ways in which organizations can learn, firstly by learning of its members, and secondly by hiring new members with new knowledge (Nahapiet, Ghoshal, 1998). Therefore knowledge is, unlike traditional factors of production, intangible (Fong, 2003), and cannot easily be captured and transferred across contexts, as it cannot be separated from the knower (Fernie *et al.,* 2003; Alguezaui, Filieri, 2010).

The literature exhibits a general disagreement on defining KM. The multiplicity of definitions derives from several diverse approaches and levels of analysis. Kamara *et al.* (2002) for instance state that there are two main approaches to KM which can be classified as 'supply driven' and 'demand driven'. According to Ugwu (2005), this was a major progress in mainstream KM, from supply driven processes focused on 'getting the right information to the right people at the right time', to a demand driven one, with a focus on both, knowledge production and knowledge integration. In addition, there are two dominant mind sets, 'functionalist' and 'interpretivist', described by Ragsdell (2009). Recently there has been a shift from a functionalist perspective to a more interpretive one, which aligns with the emergence of new generations of KM that are more concerned with managing tacit, rather than explicit knowledge, and increasingly stress the notions of social interaction and learning, rather than the role of technology (McElroy, 2003; McDermott, 2010).

It is more and more acknowledged that knowledge is essentially social in the way that it must be communicated through social action, such as knowledge 'bas' or communities of practice (Depres, Chauvel, 1999; Lu, Sexton, 2007). This approach is especially interesting in the context of this study. As argued in the previous section, the kind of knowledge the construction project team is dealing with, is a mix of tacit and explicit knowledge, but mainly 'know-how' in terms of how to install new sustainable building materials and technologies into a well-performing built result. Hence the approach of managing and sharing knowledge through social interaction is taken into account through a social network analysis approach which is further explored in Chapter 4.

The diversity of different approaches leads straight to the difficulty of defining KM precisely, as Egbu (2004) states that there is no single unified meaning of the concept in literature. Already in 1998, Ives declared that KM is an emerging discipline without any agreed-upon industry-standard definition, or a framework in which to align different fields. Furthermore Depres and Chauvel (1999) support this view by stating that 'the majority of popular and even serious work on knowledge management ignores a theory of knowledge itself [...] that is to give a definition of what they are dealing with'. However, KM is not a new concept, it was just 'newly framed and enabled by new technologies, media, devices and techniques', when it became popular in the 1990s (Ives *et al.,* 1998). The processes are more and more concerned with the whole KM life cycle and the tools to facilitate these (Carrillo, Anumba, 2002). Over a decade ago, Ives *et al.* (1998) put forward that there are many different interpretations as to what KM means and how to effectively use its potential power, but as industry experience is gained and academics continue research in this field, there will be an increased understanding, and in time an alignment. However, so far this is still not the case (Ragsdell, 2009).

Following this shortage on a unified definition, there seem to be various divisions of the KM life cycle depending on the degree of detail. Ruggles (1997) for instance, identified three categories of the KM life cycle as generate, codify and transfer, while Tiwana (2000) identified five categories as creation, location, capture, sharing and use of knowledge. Whereas Depres and Chauvel (1999) describe the KM life cycle even more detailed with six overlapping categories in their so-called event chain, shown in Figure 3.1. As the focus of this study is on the KT various aspects of the KM life cycle are important, i.e. not only the actual transfer of knowledge, but also codify the knowledge for a successful transfer and the apply and re-use it.

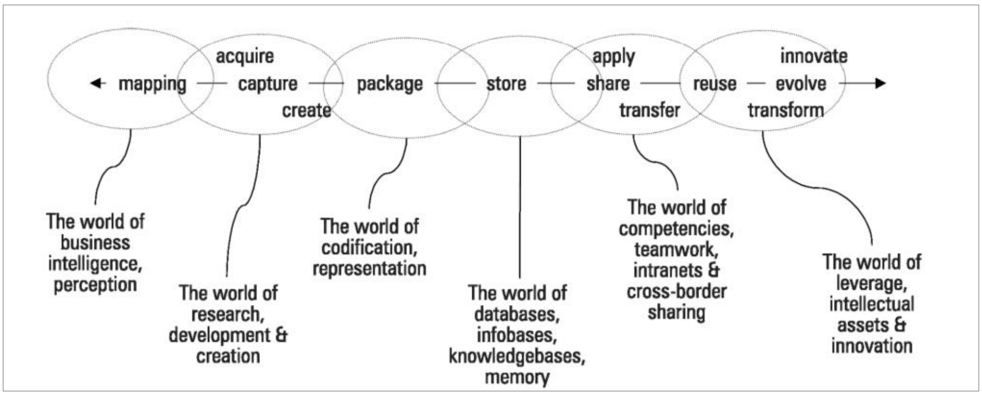


Figure 3.1: The knowledge management event chain (Depres and Chauvel, 1999)

The increasing importance of sustainability has vital consequences, not only on the technological practice of construction industry, but also on its structure and its communication channels (Rohrbacher, 2001). With the required knowledge on how to build sustainably residing in various participants of a sustainable construction project, the transfer of this knowledge seems to be the most important element of KM. Additionally it was recently argued that it is important to support the knowledge flow of not only explicit, but also tacit knowledge during a sustainable construction project (Thomson *et al.,* 2010). It seems as if generating knowledge during the design stage and codifying it into drawings is not an issue. The sustainable design intent seems to fulfil the requirements of e.g. the BREEAM design certificate. This could be due to a higher educational background, thus skills and awareness of professionals involved in the design process compared to the construction workforce. This aspect was further explored during fieldwork. As a result this study rather focuses on how to transfer and apply this specialised knowledge between the various project participants during construction stage.

Since KM is very contextual, the next section focuses on KM in the built environment.

3.3.1. Significance of Knowledge Management in the Built Environment

KM was relatively new within the built environment in the early 2000s (Carillo, Anumba, 2002). Most of the subsequent research focuses on knowledge creation within project environments or organisations, and gaining competitive advantage through it (Egbu, 2004; Kamara *et al.,* 2002; Kurul *et al.,* 2007). Carrillo *et al.* (2000; in Kamara *et al.,* 2002) declare that most of the earlier work also focused on the delivery of technological solutions, presumably due to the growth in knowledge-based and expert systems in the 1980s and early 1990s. Further research was conducted on the use of IT networks to enhance knowledge transfer in construction teams (El-Tayeh, 2008), while others (McDermott, 1999; Egbu, 2004; Fernie *et al.,* 2003) argue that KM is not only about databases. Carrillo and Anumba (2002) confirm the strong focus on sharing knowledge using electronic means in the past, while little attention was paid to other aspects of KM, regarding the use of non-IT tools. They suggest that companies should realize that KM is not only about providing an intranet (ibid). Davenport and Prusak (1998) expand on this by saying that the process of KM in organisations relies more on face-to-face interaction of people, than on static reports and databases, as Davenport *et al.* (1998; in Ives, 1998) found out that scientists and engineers tend to exchange knowledge in direct proportion to the level of personal contact. This goes along with the previous argument in section 3.2, as tacit knowledge cannot be easily transferred through IT tools, and rather requires personal contact.

KM is of great significance in a project based sector as the construction industry which is challenged by the need to capture and transfer knowledge within an environment of temporary multidisciplinary project teams (Kamara *et al.,* 2002). Each project is unique in terms of design and construction, and faces many restraints due to limited space, increasing complexity, limited budgets, tight programmes and constant demand for innovation (Fong, 2003). The fragmented nature in which the industry is organized means that efficiency in project delivery is less than expected, resulting in dissatisfied clients and low profitability for construction firms (Carrillo *et al.,* 2000; in Kamara *et al.,* 2002). Some key characteristics of construction industry products, such as immobility, complexity, durability, or costliness have resulted in a low level of mass production, regionalism and a gap between design and construction (Rohrbacher, 2001). Therefore attempts to develop ‘one-size-fits-all’ solutions to KM problems in the construction industry are unlikely to be successful (Dixon, 2000). Nonetheless some elements of knowledge management have always been practised within the construction industry, whether in the form of codes of practice, lessons learnt or in the use of IT applications (Carrillo, Anumba, 2002).

Kamara *et al.* (2002) assess strategies for KM in the architecture, engineering and construction industry. They argue that effective KM requires a combination of both mechanistic and organic approaches in an integrated approach that incorporates both technological and organizational issues. Moreover they put forward that the basic strategy is more people centred, than focused on IT tools. The motivation for managing knowledge is mainly about improved efficiency in project delivery. Regarding especially KT in construction industry, it was discovered that some constraints derive from used mechanisms (Kamara *et al.,* 2002). For instance, the reliance on informal relationships can be less effective, if staff is not co-located. There can also be constraints in sharing knowledge through framework agreements, because members within the framework may be in competition elsewhere and may not always be willing to share their knowledge with other members. Various studies on KM indicate that the practice of KM in the construction sector is more influenced by contextual factors rather than content issues (Kamara *et al.,* 2002).

The construction industry is a strong knowledge-based industry, which relies heavily on the knowledge input by the different project participants (Carrillo, Anumba, 2002). The structure of project teams in construction industry is mainly determined by the contractual arrangements that underlie project practices (Kurul *et al.,* 2006). These project team configurations have a high influence on the network structure, influencing both knowledge creation capability and absorptive capacity of teams (Kurul *et al.,* 2007). It is widely acknowledged that all team members should be included in the KM process (Egbu, 2004). There is a very diverse range of professions within the sector, from the brick-layer to the investment consultant (Knight, Ruddock, 2008), with complex relationships between them (Atkinson, Yates, Wyatt, 2009), as illustrated in Figure 3.2, but all carrying different kinds of knowledge that contribute to the project. Therefore KM within the construction industry is basically people-centred and thus involves mostly the management of tacit knowledge (Kamara *et al.,* 2002).

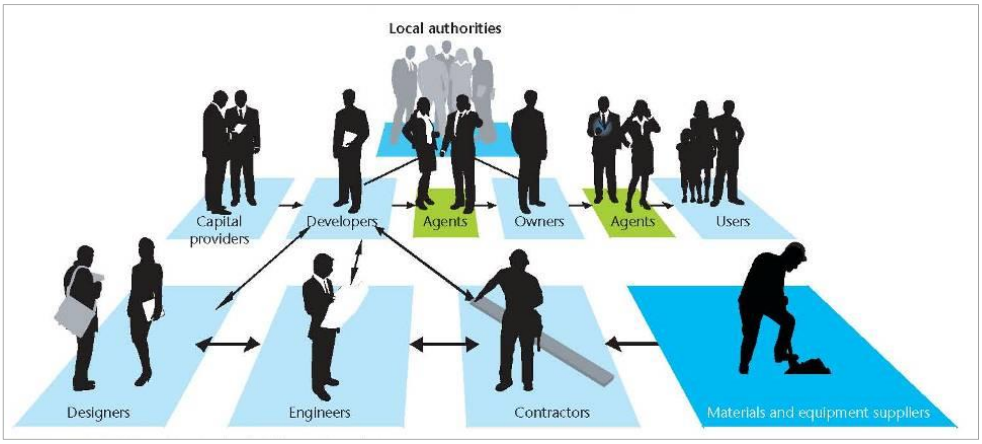


Figure 3.2: Relationships in the building value chain (WBCSD, 2008)

Furthermore the requirements for KM within this industry can be discussed under two interrelated categories: management of knowledge within projects, and management of knowledge within firms (Kamara *et al.,* 2002). An additional challenge for KM within projects is in transferring knowledge between different stages of a project (Wallbank, Price, 2007), and additionally across different projects. Through this the effective reuse of project knowledge becomes more important (Kamara *et al.,* 2002). Moreover there might occur difficulties with the transfer of knowledge between all different companies involved in one specific construction project, not only because they may have totally different KM strategies (Carrillo, Anumba, 2002), but also because they do not always want to share their knowledge in order to retain their competitive advantage (Sharkie, 2003; Bou-Llusar, Segarra-Ciprés, 2006). Besides the participants might possess different knowledge related to their area of expertise. As a result this renders KM processes within construction projects more demanding than inside the various construction firms. Furthermore this background combined with the increased complexity of sustainable construction projects (Meyer, 2008) could provide an explanation for the difficulty in putting a sustainable design into a well-performing built result.

Characteristics such as professional silos with their own knowledge and language render knowledge transfer in construction project teams even more difficult (Bresnen *et al.,* 2003). This fragmentation, illustrated in Figure 3.3, has vital implications for developing shared perspectives on innovation, knowledge and learning (Bresnen *et al.,* 2003). Especially the flow of resources, as personnel and information, across time and space, from one project to the next or even between project stages, impede capturing and transferring knowledge, and therefore risk to 'reinvent the wheel' (ibid). Most knowledge generated in one project, is buried in unread reports, or simply lost due to personnel turn-over. A failure to transfer this knowledge leads to wasted activity and impaired project performance (Carrillo, Anumba, 2002). The project teams are challenged by the need to incorporate new information into their understanding in order to solve the technical challenges they face, and thus fulfil ever-changing needs (Fong, 2003). This is even more important nowadays as sustainability issues are changing industry standards (Nelson, 2008), as argued in Chapter 2.

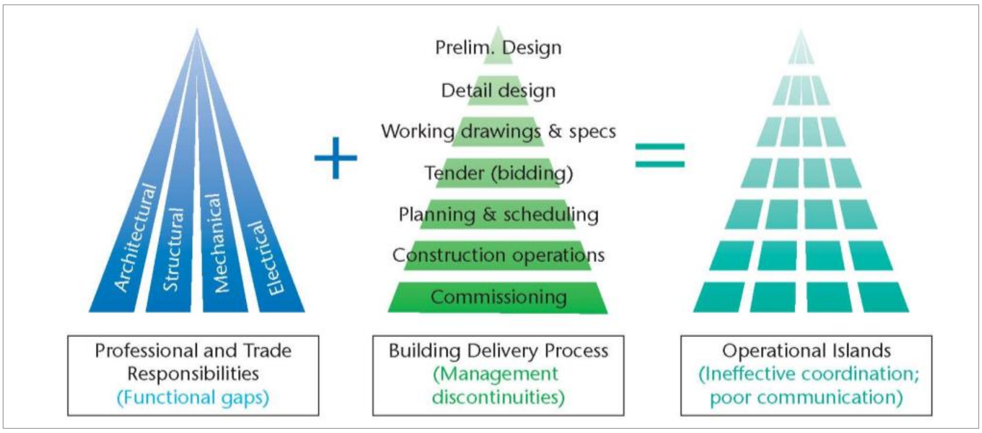


Figure 3.3: Players and practices in the building market (WBCSD, 2008)

The nature of construction project teams is both intellectually demanding and interactive. It is intellectual, because it requires the team to find new solutions to complex problems, and interactive as constant cooperation between all participants is needed (Fong, 2003). Fong (2003) puts forward that work at group-level is often 'devoted to carrying out pre-defined tasks rather than maintaining dialogue, through which tasks are newly defined and further developed'. The efficiency of such cross-functional project teams depends very much on coordination, common knowledge and organizational structure (Häkkinen and Belloni, 2011), thus the way in which team members mobilize their social capital and diffuse project awareness amongst each other (Huang, Newell, 2003).

Riege (2005) found out that small and medium sized companies (SME) tend to provide an environment that is conducive to generating knowledge, mainly due to their size and closer social relationships of employees, resulting in good communication flows and knowledge sharing. This aspect is especially important and positive, as the majority of the UK construction industry consists out of SMEs (Lu, Sexton, 2007). This could indicate a major possibility for improving KT within various teams/companies participating at one sustainable construction project, if the companies delivering sustainable buildings are also SMEs.

3.3.2. Innovation: Managing Knowledge on Sustainable Construction

As previously stated, the basic motivation for the management of knowledge is more about improving efficiency in project delivery, than generating of new knowledge or effective management of fast changing knowledge to gain competitive advantage (Kamara *et al.,* 2002). However, it is important to point out that the project participants are engaged with a constantly developing and thus fast changing knowledge while dealing with sustainable building materials, technologies and techniques, due to high-paced technical improvements. Consequently the generation of new knowledge and innovation is part of the KM on sustainable construction, with the diversity of knowledge as one of the main factors for innovation (Cohen, Levinthal, 1990).

While discussing innovation, Cohen and Levinthal (1990) state that outside sources of knowledge are often critical to the innovation process, as most innovations result rather from borrowing than inventing. This innovative capability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends, is defined by Cohen and Levinthal (1990) as 'absorptive capacity'. Hereby prior related knowledge is important for the process, as a diverse background provides a better base for learning (McDermott, 1999), because it increases the prospect that incoming information will relate to something that is already known. Yet, it has to be considered that adults always enter knowledge sharing situations with their set of existing skills (Gerber, 1998). However, prior experience with learning a task does not necessarily improve performance, because an individual knows how to learn (Cohen, Levinthal, 1990). Enhanced knowledge often comes out of interaction of two points of view (Ives, 1998). Hansen (2002) ascertains that teams, who have worked with each other before, have established some heuristics for working together, reducing the time to transfer non-codified knowledge, explain it and understand each other. Nonetheless a firm's 'absorptive capacity' is not simply the sum of the absorptive capacities of its employees (Cohen, Levinthal, 1990). But this heavy reliance on people and the assumption that they will transfer their learning from one project to the next makes organizations vulnerable, especially when there is a high staff turnover (Kamara *et al.,* 2002).

Furthermore 'absorptive capacity' also depends on the individuals, who stand at the interface of either the firm and the external environment, or between subunits within the firm (Cohen and Levinthal, 1990). These individuals are also referred to as 'gatekeeper' or 'boundary-spanner' in social network literature. This person scans and interprets the team's environment and then passes on information to the rest of the team (Hansen, 2002). Even within a firm, different sub-units might possess different competencies and hence are useful for teams that seek their knowledge (ibid). However, assessing the value of a resource might be difficult because of the heterogeneity of resources (Grant, 1996). Moreover it has to be considered that the maintenance costs involved in keeping this network, might lead to a longer project completion time (Hansen, 2002). As a result critical knowledge is also about the awareness of where useful complementary expertise resides, within and outside the organization. This is especially important within a construction project, as it usually involves various companies. It is widely accepted that one main difficulty lies in losing competitive advantage by transferring knowledge between different participating companies (Argote and Ingram, 2000; Ermine *et al.,* 2006). However, it has to be acknowledged that in construction industry every company has its own field of expertise, even more so with sustainability changing the industry. Therefore one of the main tasks of KM in this sector could be on how to transfer knowledge between the various participating companies in one construction project without fearing to lose the competitive advantage.

The organisational culture plays an important role with its maintenance support for capabilities through socialisation of new employees (Grant, 1996). As previously argued, most of the new knowledge on sustainable construction to be managed and transferred is a combination of explicit and tacit knowledge. Since tacit knowledge consists of truth, beliefs, perspectives, concepts, judgements, expectations, methodologies and know-how, the nature of innovation and KM are very complex social processes (Egbu, 2004). Hence the very diverse range of participants on a construction project could on the one hand help developing process innovation for sustainable building techniques through better exchange of their diverse knowledge, while on the other hand competition between them could constrain it (Sharkie, 2003).

As previously argued, innovations occur through cooperation and continuous interaction between a firm and other external actors (Alguezaui, Filieri, 2010). Previous research on innovations defined two main categories of innovation depending on their novelty: incremental and radical (Henderson, Clark, 1990; Garcia, Calantone, 2002; Gatignon *et al.,* 2002; in Alguezaui, Filieri, 2010). Incremental innovation implies only small changes to a company's current products, services or processes. While radical innovation refers to novel combination of different fields of expertise resulting in totally new technological patterns. This is very disruptive for the conduct of business and is associated with exploration and competence destruction (Anderson, Tushman, 1990; in Alguezaui, Filieri, 2010). Moreover radical innovations rely more on external sources of innovation than within the firm (Laursen and Salter, 2006; in Alguezaui, Filieri, 2010). As previously argued, sustainability issues are changing the definition of tasks within construction industry (Kamara *et al.,* 2002; Häkkinen, Belloni, 2011), with difficulties emerging from fast technical changes (Thomson *et al.,* 2010). Therefore innovation is needed by practitioners in the field. However, it very much depends on their trade, whether an incremental or radical innovation is needed.

Sustainability caused a paradigm change in construction industry (Rohrbacher, 2001). The nature of projects where the ultimate goal is to deliver a green building is more complex than standard ones (Meyer, 2008). This is due to the increased number of people involved, but also because of modified technical knowledge. Furthermore the supply-chains of new sustainable building materials are more distributed than of conventional ones. Sustainable buildings require high-tech components, which are supplied by specialized companies, e.g. building control technologies or use of solar energy. Thus various sorts of new services and consultancies become important, as high level of expertise is required for solving the complex problems of ecological optimization (Rohrbacher, 2001). Some of those new companies entering the market are traditional actors reorienting themselves, followed by others, who will be trained in these new professions in the long run. However, this requires a paradigm change in vocational training and institutional procedure (Rohrbacher, 2001).

Roy *et al.* (2003) declare that one of the main problems of KT is that producers and users of knowledge both lack each other’s knowledge base. This leads to a gap, where knowledge is maybe transferred but not applied. Although the study of Roy *et al.* (2003) is in the area of workplace health and safety knowledge, this approach can easily be applied to construction industry. One could argue that designers do not possess the knowledge of the operatives on how to put drawings into a built result, and the other way around. For this reason a KT from the operatives towards the professionals could be suggested, or at least some sort of participation of operatives during the design stage (Ugwu, 2005).

Highly efficient green buildings cannot be properly constructed without better co-operation and integration of the various actors, i.e. suppliers, professionals and users. The functional dependencies of diverse components are stronger and much more complex compared to conventional buildings, i.e. sustainable buildings are more ‘machine-like’ (ibid). Therefore Rohrbacher (2001) suggests new procedures, such as the so-called ‘integrative planning process’, involving various professionals and energy experts from an early project stage on, which can avoid expensive revisions and disruptions later on in the construction process (WBCSD, 2009). This interdisciplinary collaboration from the very start of a project is also a way to enhance knowledge sharing (Gluch *et al.,* 2012). Häkkinen and Belloni (2011) support this by stating that all expertise and knowledge is already needed at the beginning of a project. This requires close interaction and effective communication between all participants. Additionally, new ways of certifying components and new ways of quality control of the built result (Rohrbacher, 2001), as presented in section 2.4, can support a better quality standard, and thus provide a mean to overcome the performance gap.

3.3.3. Key Concepts in the Area of Knowledge Management

In line with the first research objective presented in Chapter 1, this section explores four key concepts in the area of KM which contributed to the development of the conceptual framework of this study presented in Chapter 5.

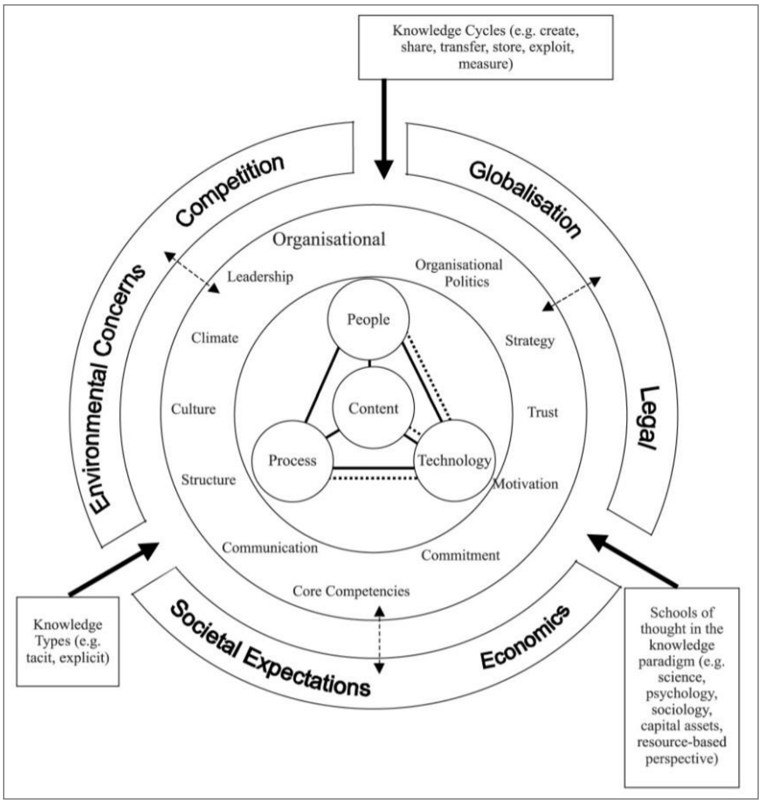


Figure 3.4: A conceptual model of the main factors associated with KM in project based environments (Egbu et al., 2001; in Egbu, 2004)

Figure 3.4 presents the conceptual model by Egbu *et al.* (2001; in Egbu, 2004). It shows the complex relationships between knowledge, intellectual capital and organizational innovations (ibid). In the centre of the framework are four dimensions: people, content, technology and process. Hence the importance of the KM process itself is taken into account. Moreover this concept describes a much wider context than earlier frameworks, as it considers factors such as globalisation and the three pillars of sustainability, described in section 2.2. This implies that a change in context through environmental concerns also implicates a change of KM practices. Thus it goes along with the argument of sustainability changing the industry context and hence adjusted KM practices are needed (Kamara *et al.,* 2002; Cohen, Levinthal, 1990). However, the model does not indicate the direction of change, nor does it explain the dependencies of the various factors.

Depres and Chauvel's (1999, 2002) KM concept is based on the deconstruction of 72 published KM models. Following this, they developed a framework existing out of six basic structuring dimensions, identified as:

- Phenomena
- Action
- Level
- Knowledge
- Technology
- Outcomes

Enablers and barriers associated with KM are defined as structural or functional conditions that are responsible for the success or failure of a KM initiative. Although this concept was developed over a decade ago, it is still current and important, as it identifies several main aspects of KM.

Another key concept is the framework of CLEVER developed by Carrillo and Anumba (2002) as part of a twenty-month UK government-funded research project on 'Cross sectoral LEarning in the Virtual entERprise' (CLEVER). The intention of this project was to explore the characteristics of KM in different industry sectors in order to derive a cross-sectoral framework that supports companies in selecting KM processes best suited for their circumstances. This indicates that knowledge is always contextual and thus every KM initiative has to be different regarding its context. One could argue that this framework shows some similar dimensions to Despres and Chauvel's approach (2002), as follows:

- 'knowledge base' resembles → 'knowledge'
- 'knowledge management process' resembles → 'action'
- 'performance measurement' resembles → 'outcome'

Hence this framework can be seen as a form of verification of Depres and Chauvel's framework (1999). However, Carrillo and Anumba (2002) moved on, as they put the factors in relation with each other. Nevertheless it has to be questioned, why the KM process is not allocated in the centre of the framework, as due to its importance, i.e. the other three dimensions would lose their meaning, if the knowledge management process fails.

The dimensions of Depres and Chauvel's (1999, 2002) and Carrillo and Anumba's (2002) KM concepts were taken into account, when developing the main dimensions of the conceptual framework which were defined as follows:

Knowledge Input →Knowledge Transfer Process →Output

While the structural and functional conditions defined by Depres and Chauvel (1999, 2002) as the potential enablers and barriers were termed as 'general KT enhancers and inhibitors' and allocated to the knowledge transfer process. A more detailed description of the conceptual framework is provided in Chapter 5.

Another interesting approach is presented by Ermine *et al.* (2006) who suggest a concept of knowledge domains that could offer great possibilities to analyse and enhance productive use of knowledge in companies. Hereby they highlight the location of knowledge domains by the successive analysis of e.g. activities, projects, products, and draw a map according to it (ibid). If this concept of knowledge domains is applied to a construction project, it could indicate the location of where which knowledge resides inside each participating team. Identifying the repositories of knowledge on how to build sustainably could then ease the next step in the KM life-cycle, i.e. the transfer of it. It was decided to follow this approach in terms of the importance of identifying the anticipant source of knowledge.

3.4. Knowledge Transfer

As previously argued, knowledge transfer (KT) is one part of the KM life cycle (Despres, Chauvel, 1999). It can be seen as the most important aspect of it (Wilkesmann *et al.,* 2009), because if the transfer is not successful then the whole KM process fails. Its constraints can be found at many different levels. While discussing KT, it is important to first declare the three main components of it, as knowledge source, knowledge recipient, and the process of knowledge transfer itself. As a result the remainder of this section is organised accordingly.

3.4.1. The Knowledge Source and Recipient

Following Ermine *et al.* (2006) it is vital to determine the so-called knowledge domains in order to better explore the knowledge sources in a sustainable construction project. The repositories of knowledge in construction projects, i.e. the anticipant source, can be found on three levels, regardless of the type of knowledge. The first one is within the team, i.e. company working on one particular construction project. The second one is within other teams, i.e. other companies, engaged in the same construction project. The third source is outside of that specific construction project. Argote and Ingram (2000) state that there are three repositories for knowledge in organisations, i.e. members, tools, and tasks, and various possibilities formed by combining these. Members are the human components of organisations, tools are the technological components, and tasks reflect the organisation's processes. Therefore tools could represent any kind of printed or IT based resource. Human components are called actors in line with social network literature. As a result the anticipant sources of knowledge were defined as follows:

- Inside the team
- Actors
- Printed/ online resources
- Outside the team
- Actors
- Printed/ online resources
- Organisation/ company
- Outside this specific construction project
- Actors
- Printed/ online resources
- Institutions

The recipient of knowledge is foremost considered as a human being (McDermott, 1999), in this case someone working on the sustainable construction project. Reagans and McEvily's (2003) stress personal capacities of people involved in KT. They argue that participants must have a certain capability of knowledge combination, common knowledge, as well as individual ability, in terms of framing and translating knowledge. Other positive factors are e.g. common knowledge, which hereby refers to the common understanding of a subject area shared by those engaged in the KT process (Huang, Newell, 2003). As previously argued in section 3.3.2, every adult participating in a KT process in a work environment has his/her own individual set of knowledge, skills and interpretations (Gerber, 1998). Furthermore it has to be considered that each person is different in many ways, such as gender, age, cultural background and experience. These factors should be taken into account while examining KT, as they could influence the KT process. This is also in line with the second research objective, i.e. identifying factors that influence KT on how to build sustainably. As a result these potentially influencing factors are further explored and defined in the following sections.

3.4.1.1. Nationality and Hierarchical Levels

Wilkesmann *et al.* (2009) follow Hofstede (1994) in emphasizing the effect of four national cultural characteristics of KT participants on KT as power distance, performance orientation, in-group collectivism and uncertainty avoidance.

These characteristics might result into differences regarding the findings of the countries under examination, i.e. Germany and the UK. For instance in societies with high uncertainty avoidance, such as Germany, KT can be supported through clear responsibilities for topics, tools or administration rights (Wilkesmann *et al.,* 2009). This form of cultural awareness is also highlighted by Ruddy (2000).

Furthermore power distance seems to be not very dominant in Germany. However, power distance depends very much on the structure of an organisation, even if employees from the lower hierarchical levels transfer their knowledge bottom-up. Thus companies acknowledging the importance of KT tend to keep hierarchy differences rather low, and try to create an atmosphere of equality and openness between hierarchic levels (Wilkesmann *et al.,* 2009). Therefore low power distance supports intrinsic motivation and a voluntary KT in a bottom-up direction. These disadvantages of hierarchical organisational structures for knowledge sharing are also supported by Rydin *et al.* (2007). If a culture is very performance oriented, achievement must be visible and measurable, because it involves a rewarding scheme for employees. In-group collectivism can enhance KT within groups, while high uncertainty avoidance rather inhibits it (Wilkesmann *et al.,* 2009).

These national cultural characteristics are part of each individual participating in a KT process, whether as source or recipient, and thus are vital for its success. Therefore the cultural background is one of the so-called general actor attributes in the conceptual framework developed in the due course of this study and presented in Chapter 5. The term ‘nationality’ is used to express the cultural background of KT participants, though it has to be acknowledged that this might be limited to fully capture the multi-cultural backgrounds of some respondents. Findings on this issue can be found in Chapters 6 and 7.

3.4.1.2. ‘Who knows What?’

As team members become familiar with each other, they develop a trusting relationship, which determines the type of knowledge that they are comfortable in sharing with each other. A power struggle can arise especially in the early forming stage of a team, which can also be influenced by the organisational climate (Sun, Scott, 2005). Moreover Moreland and Myaskovsky (2000) name anxiety about acceptance, interpersonal conflicts and uncertainty about group norms as common problems of new teams. The perceived competency of individuals by the team determines the extent of KT by the team to the individual (Sun, Scott, 2005). Thus lack of perceived competency can be a significant barrier of KT.

However, over time and with experience of working together, teams improve their performance by acquiring knowledge of ‘who knows what’ (Berends, 2005), which was termed ‘transactive memory’ by Wegner *et al.* (1991), although more in the context of couples. Moreland and Myaskovsky (2000) investigate the creation of ‘transactive memory systems’, i.e. embed knowledge of who is good at performing which tasks, and who is good at operating which tools in work groups. Hereby providing feedback about individual skills and communicating these were found to be even more effective than training individuals. The knowledge of ‘who knows what’ can be gained through e.g. being trained together. Furthermore, the performance of groups with well-developed ‘transactive memory systems’ seems to exceed that of groups lacking such systems (ibid). This aspect is very important in the context of a construction project, as it involves various teams performing different tasks. Hence, while the knowledge on ‘who knows what’ is probably possessed by the members of each team/company, it is unclear as to what scale each team possesses this knowledge of other participating teams/companies on the same project.

3.4.1.3. Motivation for Knowledge Transfer

An employee’s productivity is influenced by situational and motivational factors. Since tacit knowledge of individuals is an essential component of organizational success, the employee must be sufficiently motivated to share it (Egbu, 2004). Incentives for being active in the KT process vary from external rewards to intrinsic factors (Ragsdell, 2009). This involves good people management as well, where trust itself can already be an incentive (Egbu, 2004). Trust also matters in problem-framing interactions, i.e. willingness to expose lack of knowledge and explore alternative solutions (Borgatti, Cross, 2003). It can be assumed that construction teams have developed long-lasting trust-based relationships amidst working colleagues within their teams, while it is rather unlikely that they would expose a lack of knowledge to other teams/companies involved at the same project. Brookes *et al.* (2006) support this by emphasizing factors that enhance project KM as trust, respect, longevity of relationships and shared professional and educational experience.

Besides it is necessary to consider that knowledge workers, project staff and team members, should all be included in a dynamic KM process (Egbu, 2004). Hereby all employees should be encouraged to develop some kind of project awareness and emotional attachment through promoting the importance of cross-functional collaboration (Huang and Newell, 2003). This goes along with Rohrbacher’s (2001) approach of the so-called ‘integrative planning process’ in which all project participants are involved from project initiation onwards, as previously presented. Measurement and reward schemes are essential in such a performance oriented context (Wilkesmann *et al.,* 2009). However, it has to be acknowledged in this context that practical ‘know-how’, which has been appreciated in e.g. craftsmanship, has not been financially rewarded to the same extent as cognitive education as a form of ‘know-that’ (Haldin-Herrgard, 2000).

Furthermore Wilkesmann *et al.* (2009) found out that the norm of reciprocity is another very important aspect, as often an employee provides knowledge to another employee only if he/she can expect that in return the other person will provide knowledge to him/her in the future. This likelihood of reciprocity suggests again KT rather occurring inside each construction team than in between various participating teams/companies, as it is unlikely that people from different companies work together on other building projects.

Other dimensions with a rather low effect on KT are for instance assertiveness, gender, stable hierarchies, obedience and respect towards status, age, societal roles, and positions (Wilkesmann *et al.,* 2009).

In keeping with the research objectives presented in Chapter 1, these general influencing KT factors were taken into account when developing the conceptual framework. The factors discussed in this section were categorised as so-called ‘general actor attributes’:

- Nationality/cultural background
- Gender
- Age/ Experience
- Hierarchical levels/ job roles/ levels

Since the process of the actual KT can be very diverse and crucial for the success of it, the next section will explore this aspect further.

3.4.2. The Knowledge Transfer Process and Methods

3.4.2.1. Vital Preconditions for Knowledge Transfer

According to Nahapiet and Ghoshal (1998) three conditions must be satisfied for knowledge transfer to take place: there must be an opportunity to make the exchange, the parties must anticipate the interaction and be motivated for knowledge sharing. Whereas van Wijk *et al.* (2008) emphasize three crucial factors influencing KT as knowledge characteristics, organizational characteristics and network characteristics. The aspect of social networks within teams and projects effecting KT appears quite often in KM literature (e.g. Snowden, 2003; McElroy, 2003; McDermott, 2010; Lu and Sexton, 2007). This approach was taken into account and is further explored in Chapter 4.

3.4.2.2. Time to transfer Knowledge

Shared knowledge stays with the giver, while enriching the receiver (Egbu, 2004). But still KT is a cost to the source, regarding time and effort. Thus it is more likely that a transfer will occur and be successful the easier it is, as for less time and effort required (Hansen, 2002). Snowden (2003) states very absolutely that ‘time is the main enemy of KM.’ Therefore the ease of transfer is one of the main explanations for some knowledge transfer taking place and others not. Nevertheless, it has to be considered that the time spent on just maintaining direct contacts, is time not spent on other professional tasks (ibid). The focus on day-to-day business is often one of the reasons why a KT is unsuccessful or not happening at all (Lu and Sexton, 2007). The factor time-efficiency is also emphasized by Rydin *et al.* (2007) for the context of sustainable construction.

Furthermore every relation implies different costs, i.e. advice-seeking relations need to be maintained, while advice-giving relations require time helping others (Hansen, 2002). Interestingly, although this aspect of cost emerged as an important factor in prior qualitative research (Cross and Borgatti, 2000), Borgatti and Cross (2003) found out that it was not statistically significant for the participants. Nevertheless the factor ‘time’ was acknowledged as a KT influencing factor and fed into the development of the conceptual framework of this study. Findings on this issue can be found in Chapters 6 and 7.

3.4.2.3. The Path of Knowledge – Unpacking the ‘Knowledge Transfer box’

While literature has named various KT methods, the process itself is more or less treated as a black box (Berends, 2005). The KT process could be described as the result of defining what knowledge and what amount of it, is transferred from which source to which recipient, defining its path and direction, how much time was spent, which method was used, which circumstances were facilitating or hindering it, and whether it was a successful transfer. A complete understanding of all these aspects is required to fully analyse and understand one single KT process, as all differ from each other regarding these variables. This can be considered as the actual challenge of this research, as to fully understand every KT occurring in a sustainable construction project in order to enhance it.

When focusing on the KT process it can be argued that the most important aspect are the various methods used in order to transfer the knowledge. There are many different methods to transfer knowledge, some even without the recipient being able to articulate the knowledge he/she has received (Argote and Ingram, 2000). Knowledge does not necessarily have to be articulated for being transferred (Reagans, McEvily, 2003). KT is regarded as a multitude of processes taking place directly with (externalisation) or without language (socialisation). Socialisation is a valuable mode of transferring knowledge in work teams even without language, e.g. through imitation, observation and sharing experiences face-to-face (Fong, 2003). Individual effort and motivation are important factors hereby (Reagans and McEvily, 2003). Moreover through collaboration and by forming long term relationships, construction organisations are able to learn from projects, transfer knowledge to organizational base and along supply chains (Egbu, 2004). An important aspect is that there are open spaces or other environments promoting interaction among employees, as knowledge is developed through social interventions (Borgatti, Cross, 2003).

As argued in section 3.2, the type of knowledge to be transferred has to be considered, since each type is best transferred differently. The dualist framework tacit and explicit co-exists in a synergetic relationship (Gill, 2000). Thomson *et al.* (2010) emphasize the more significant role of tacit knowledge in sustainable construction projects compared to explicit knowledge in form of e.g. documents. Tacit knowledge cannot be given in lectures or found in databases, textbooks, manuals or newsletters for diffusion. As a result it cannot be managed, hence taught the same way as explicit knowledge (Haldin-Herrgard, 2000). Hence the KT process of tacit knowledge appears to be more difficult, than the one of explicit.

In working life we find tacit knowledge embodied in intuition, rule-of-thumb, gut feeling and personal skills. These can be classified into two dimensions, the technical and the cognitive dimension. The technical dimension encompasses information and expertise in relation to ‘know-how’, and the cognitive dimension consists more of beliefs and values (Gore, Gore, 1999; in Haldin-Herrgard, 2000). Since individuals are the primary repositories of tacit knowledge, it makes it difficult to transfer it (Haldin-Herrgard, 2000). This is due to the main characteristic of tacit knowledge, as its difficulty in being coded and shared. However, there are two different approaches in order to solve this: either tacit knowledge must be made explicit for easier sharing, or tacit knowledge will just stay tacit (ibid). This means other sharing methods have to be used in order to successfully transfer this tacit knowledge. Conversion of tacit knowledge to explicit or at least finding ways to transfer it, could offer great value to organizations, but is not the focus of this research. It is rather assumed that the explicit knowledge on sustainable construction is easier to transfer. Thus it is more important to concentrate on KT methods for tacit knowledge.

Methods to share tacit knowledge were identified as follows (Gerber 1998; McDermott, 1999; Haldin-Herrgard, 2000; Snowden, 2003; Egbu, 2004; Lu and Sexton, 2007):

- Interaction with other people
- Practical experience
- Reflection
- Internalization
- Individual talents
- Exercise
- Face-to-face interaction/ direct interaction
- Apprenticeship/ apprentice systems
- Action learning
- Networking
- Communities of practice
- Story telling
- Coaching
- Mentoring
- Quality circles
- Knowledge bas

When focusing on construction industry Ugwu (2005) states that there are certain knowledge dissemination mechanisms that require significant improvement. Ugwu’s study is especially important in the context of this research project, as he focuses on the development of sustainable building techniques, though in Hong Kong. He particularly mentions post-project reviews, while Riege (2005) states that in post-project reviews mistakes are normally covered up, blamed on others, explained away, rather than recognised and corrected. Furthermore Rydin *et al.* (2007) stresses the importance of assigning a knowledge worker who is an expert on sustainable construction. Other mechanisms to transfer knowledge in sustainable construction project environments mentioned by Ugwu (2005) are:

- In-house seminars (e.g. using case studies on sustainability)

- Mentoring schemes
- On-line delivery of resources
- Provision of IT tools for decision-support in infrastructure sustainability appraisal and assessment
- External training programs and services, e.g. face to face seminars
- Self-learning of individuals, e.g. on-line based and formal
- Guidelines and procedures

As a result the following methods were drawn from the previously discussed literature and represent the KT process 'box' of the conceptual framework, presented in Chapter 5:

- Communication (spoken, written)
- Pro-active approach (databases, reports, books, manuals)
- Practiced experience (internalization)/ Routines/ Repetition
- Hands-On/ Action Learning/ Direct Interaction
- Best Practice
- Mentoring/ Apprenticeship
- Reflection/ Post-Project Reviews
- Assigning Knowledge Workers
- Co-Location of Staff
- Adult Learning/ Training on-the-job
- Training off-the-job
- Networking/ Face-to-face social interaction
- IT (databases, PC programs)

3.4.2.4. Barriers of the Knowledge Transfer Path

The KT process tends to take place through three main paths, i.e. individual to team, team to organization and organization to inter-organization (Sun, Scott, 2005). There are of course other paths of transfer, e.g. from individual to individual, which is the focus of this study. As a result the barriers are to be found at the four levels, individual, team, organization, and inter-organization (Sun, Scott, 2005; Ruddy, 2000).

Table 3.2: Knowledge transfer barriers between individual and team (adapted from Sun and Scott, 2005)

KT Barriers from individual to team	KT Barriers from team to individual
Personality differences	Need to gain acceptance in the group
Skills of communication and persuasion	Can the individual be trusted?
Group confidence in the individual	Openness to ideas
Divergent objectives/ hidden agenda	Learning aptitude of individual
Fear of loss of ownership/ control of knowledge / competitive edge	Group has other aspirations than knowledge transfer
Openness to ideas	Lack of an effective communication methodology
Afraid that knowledge may be inadequate or unimpressive	Power play and group pressure
	Consolidation of group members' perception to one message

Table 3.2 presents the KT barriers between individuals and their team identified by Sun and Scott (2005). These barriers can be mainly categorised into the various aspects discussed in section 3.4.1 on knowledge source and recipient. Hence they can be classified as 'general actor attributes'. In addition these barriers also relate to the cooperative norms mentioned previously, and to the KT process itself.

3.4.2.5. Enhancing and inhibiting Factors of Knowledge Transfer

One of the main research objectives presented in Chapter 1, was to identify general enhancing and inhibiting factors of KT. These factors were discovered through a continuous literature review and categorized into six groups according to their nature. The results are summarised in Table 3.3. The factors contributed also into developing the conceptual framework for this research to be found in Chapter 5.

Most factors relate to source and recipient, also termed actors, according to the social network literature. Personal actor attributes are the first category, followed by job roles. As the KT context is a work environment, the job roles and levels do influence the KT in terms of e.g. power distance, as argued in section 3.4.2.1. This is followed by the actors' perception of the knowledge itself. As for factors not related to the actual person involved, the most important one is the KT process itself, followed by the time spent on it. IT is the last of the six categories. As previously argued IT better facilitates the transfer of explicit knowledge (McDermott, 1999; Carrillo, Anumba, 2002), thus it is not as important in the context of this study due to the significance of tacit knowledge in sustainable construction (Thomson *et al.,* 2010). Still it is mentioned here as it represents a major knowledge source and a KT method at the same time.

Table 3.3: Enhancing and inhibiting KT factors

Actor attributes (Source/ Recipient)	Job Roles / Job Level	Knowledge (Definition, Perception)	KT Process	Time of KT	IT Tools
Age differences (Riege, 2005)	Boundaries between team members of different disciplines (Fong, 2003)	Incoherent knowledge vision (Egbu, 2004)	Integration of separate knowledge flows (Bresnen *et al.*, 2003)	Time constraints and pressure on key staff/ knowledge 'experts' (Egbu, 2004)	Limits of technological and procedural mechanisms (Bresnen *et al.*, 2003)
Gender differences (Riege, 2005)	Boundaries between client, consultant and contractor (Fong, 2003)	Low awareness of the value/ benefit of possessed knowledge (Riege, 2005; Egbu, 2004)	Mechanisms for capturing project learning (Bresnen *et al.*, 2003)	Lack of contact time/ opportunity and interaction between knowledge source and recipient (Riege, 2005; Nahapiet and Ghoshal, 1998)	Fear of the use and application of IT tools for KM (technophobia) (Egbu, 2004)
Differences in personal experiences (Riege, 2005; Huang, Newell, 2003)	Lack of clear definition of roles and responsibilities (Bresnen *et al.*, 2003)	Information sharing climate (Egbu, 2004)	Appropriate methods/ tools for measuring and valuing knowledge (Egbu, 2004)	General lack of time to share knowledge (Riege, 2005)	Synchronous groupware tools (e.g. calendar and scheduling tools, electronic meeting systems, electronic whiteboards or chat tools) (Ives, 1998)
Formal education and training (Egbu, 2004)	Difficulties associated with internal structural barriers and political divisions (Bresnen *et al.*, 2003)	Standard, flexible knowledge structures (Egbu, 2004)	Adequate standardised processes (Egbu, 2004)		Asynchronous groupware tools (e.g. e-mail, knowledge repositories, group writing and document editing tools, workflow tools) (Ives, 1998)
Motivation to transfer knowledge (Nahapiet, Ghoshal, 1998)	Rivalries and competition between teams (Kamara *et al.*, 2002)	Clear purpose of KM (Egbu, 2004)	Flexible organizational structures (Egbu, 2004)		Technical infrastructure: systems to obtain, organise, restructure, memorise and distribute knowledge (e.g. intranet, internet, repositories, databases) (Egbu, 2004)

Actor attributes (Source/ Recipient)	Job Roles / Job Level	Knowledge (Definition, Perception)	KT Process	Time of KT	IT Tools
Combination capability/ capacity to assimilate and apply new knowledge (Nahapiet, Ghoshal, 1998)	Use of formal power/ strong hierarchy, position-based status, formal power 'pull rank' (Riege, 2005)	Coherent knowledge vision linked to economic performance and strategy (Egbu, 2004)	Action learning, developmental staffing practices, skill profiling systems, performance metrics, peer feedback processes (Borgatti, Cross, 2003)		Intranet: lack of standardisation of system, practical difficulties in accessing it from site offices, lack of incentives and resources to use and up-date accurately (Bresnen *et al.*, 2003)
Level of 'emotional attachment' (Huang, Newell, 2003)	Power distance/ hierarchic differences/ flows are restricted to certain direction – top-down (Wilkesmann *et al.*, 2009; Riege, 2005)	Exchange and combination will prove worthwhile (Nahapiet and Ghoshal, 1998)	Change in motivational practices, including performance management and team based rewards (Egbu, 2004)		Unwillingness to use applications due to a mismatch with needed requirements (Riege, 2005)
Knowing and valuing what another person knows and being able to gain timely access to it, plus perceiving that seeking information from that person would not be too costly (Borgatti, Cross, 2003)	Senior management support (Egbu, 2004; Riege, 2005)	'Law of increasing returns' i.e. shared knowledge stays with the giver while enriching the receiver (Egbu, 2004)	Multiple channels of KTs: dialogue with functional departments, interaction with clients/ customers and suppliers (Egbu, 2004)		Unrealistic expectations of IT systems (Riege, 2005)
Unwillingness to share knowledge because of difficulty in validating knowledge (Carrillo and Anumba, 2002)			Development of knowledge-based expert systems (Anumba *et al.*, 2000; in Kamara *et al*., 2002)		Difficulties in building, integrating and modifying technology-based systems (Riege, 2005)
Shared language (Egbu, 2004)			Use of standards and best practice guides (Kamara *et al.*, 2002)		IT systems could enhance KT between spaces (Riege, 2005)

Actor attributes (Source/ Recipient)	Job Roles / Job Level	Knowledge (Definition, Perception)	KT Process	Time of KT	IT Tools
'Knowledge is power' syndrome (Egbu, 2004)			Organizational routines (Huang, Newell, 2003)		
Poor verbal/ written communication and interpersonal skills (Riege, 2005)			Common knowledge and repetition (Huang, Newell, 2003)		
Lack of trust (Riege, 2005)			Hands-on experience (Ugwu, 2005)		
Differences in national culture (Riege, 2005)			'Newcomers' learn from 'oldtimers', i.e. mentoring (Kamara *et al.*, 2002)		
			Post-project review to capture lessons learned (Ugwu, 2005)		
			Key members of the team, critical for knowledge (Kurul *et al.*, 2007)		
			Co-location of staff (Kamara *et al.*, 2002)		
			Size of company and project (Bresnen *et al.*, 2003; Riege, 2005)		
			Formal and informal spaces to share, reflect and generate knowledge (Riege, 2005)		
			Rewards and recognition systems to motivate knowledge sharing (Riege, 2005)		
			Lack of infrastructure and resources (Riege, 2005)		

As a result the following categories were developed according to these factors and represent the general KT enhancers/ inhibitors in the conceptual framework:

- Actor attributes
- Knowledge (Definition and Perception)
- Job roles / level
- Training
- KT Process
  - KT methods/ mechanisms
  - Time

3.5. Conclusion

Chapter 2 concluded by revealing a lack of knowledge and awareness of practitioners in the field as one of the main barriers towards sustainable construction. Capturing and transferring knowledge from one stage of a building's lifecycle to the next is already difficult, but sustainability issues render this even more challenging. Therefore this chapter has presented a review and discussion of literature on knowledge management and transfer. This was done in order to determine ways of enhancing the knowledge transfer between various participants on a sustainable construction project, and hence reduce the lack of knowledge and awareness of practitioners in the field. As a result this could help closing the performance gap of sustainable buildings.

In the first section different types of knowledge to be found in literature were identified and applied to the field of sustainable construction. It was argued that defining the kind and type of new knowledge that is introduced to construction industry through sustainability could provide a more purposeful research approach to the issue. Three subject areas of knowledge emerged through sustainability issues in the built environment were identified as sustainable materials, technologies and techniques. A combination of explicit and tacit knowledge as to know-what and know-how were allocated to these areas.

In line with the first research objective presented in Chapter 1 the areas of knowledge management in general and within the context of the built environment were explored in the second section in order to identify key concepts in this area. This was followed by discussing four of these concepts in regards to their relevance to sustainable construction. The study adapted several ideas of these concepts as the basis of its own conceptual framework on knowledge transfer.

As a result the third and last section explored the area of KT in detail and defined vital components and preconditions of KT. It is argued that in order to be able to make enhancing recommendations, it is important to first fully understand the knowledge transfer process. Hence the knowledge sources and recipients in a sustainable construction project were determined on three levels, inside the immediate work team, inside the particular construction project and outside of this project. Thereafter the 'KT box' was unpacked through identifying various methods for transferring knowledge successfully. In line with the second research objective, the chapter concludes by presenting and discussing general KT enhancers/ inhibitors.

Previous research indicated that social networks could influence knowledge transfer. Fernie *et al.* (2003) put forward that knowledge is personal, and therefore knowledge sharing takes place through the interaction of individuals. Hence social community plays a vital role in enhancing or inhibiting knowledge transfer (Bresnen *et al.*, 2003). As knowledge is a set of shared beliefs constructed through social interactions and embedded within the social contexts, Fong (2003) declares that social networks are the most important vehicle for knowledge exchange, with team members deeply reliant upon colleagues, friends and ex-colleagues as resources for generating knowledge. Moreover Nahapiet and Ghoshal (1998) claim that social networks are a valuable source for new knowledge, as the 'combination and exchange of knowledge are complex social processes'. Therefore the next chapter will explore the possibilities social networks offer to enhance KT on how to build sustainably, in order to overcome the performance gap between sustainable design intent and built result.

CHAPTER 4

THE THEORY OF SOCIAL NETWORKS

4.1. Introduction

Chapter 3 explored the area of KM and KT in detail and identified a number of factors, which influence KT on how to build sustainably in construction teams. The chapter concluded with the proposal that social networks could enhance KT between various project participants and thus offer an opportunity to bridge the gap between sustainable design and built result. Therefore this chapter aims at exploring the theory of social networks and how it relates to KT.

The chapter is divided into three parts. The first section explains the connection between KT and social networks. Thereafter an overview of the concept of social networks (SN) is provided and the theory of social capital as an alternative approach is explored. This is followed by the reasoning for adopting SN theory. The second section examines concepts combining social networks with KT in order to identify social network characteristics that influence KT. Hence the last section concludes by presenting these influencing characteristics, in line with the second research objective of this study presented in Chapter 1.

By using the term ‘social network’ it is vital to explain that this term should not be confused with online networks. It rather stands for, in line with social sciences, the set of contacts or social connections among individuals or groups (Swedberg, Granovetter, 2001). Online networks are regarded as a method to transfer knowledge and a possible source of knowledge in this study.

4.2. Knowledge Transfer and Social Networks

As knowledge is a set of shared beliefs constructed through social interactions and embedded within social contexts, Fong (2003) declares that social networks are the most important vehicle for knowledge exchange, with team members deeply reliant upon colleagues, friends and ex-colleagues as resources for generating knowledge. Nahapiet and Ghoshal (1998) claim that much valuable knowledge is fundamentally socially embedded in particular situations, coactivity and relationships. Furthermore social networks help to reduce research time, e.g. through recommendations (Fong, 2003). However, the difficulty is that success depends vitally upon interpersonal connections, rather than technological mechanisms (Bresnen *et al.,* 2003). Within a project environment the personal knowledge of whom to contact, i.e. how to use the personal network for accessing knowledge, appears to be most important (ibid). This access to knowledge is defined as receiving valuable information, but also knowing who can use it, in order to provide an efficient information screening and distribution process for members of those networks (Nahapiet, Ghoshal, 1998).

Social networks between knowledge actors can also be defined as 'knowledge networks' (Augier, Vendelø, 1999; Seufert *et al.,* 1999). A challenging aspect of knowledge networks is the interconnection of different levels and areas of knowledge, i.e. the networking between various knowledge types (e.g. explicit and tacit), between different levels (e.g. individual, group, organization), and areas of knowledge (e.g. in the built environment: professionals, operatives and users) (Seufert, Seufert, 1998). A separation of these three levels of social aggregation, individuals, groups and organizations, provides greater clarity about the research approach (Depres, Chauvel, 1999). Therefore Table 4.1 presents the focus of this study. Within the different life cycle stages of KM, KT between individuals was already identified as the main research interest in the previous chapter. Since it was decided to observe the construction stage of a specific sustainable construction project, the individuals are mainly professionals and operatives, belonging to various companies, i.e. the groups, involved in the construction process. Moreover the new knowledge on how to build sustainably was previously defined as a combination of tacit and explicit. Therefore the SN approach should allow analysing the KT between these individuals and groups in order to make recommendations for an enhancement.

Table 4.1: Focus of this study inside the knowledge management life cycle

<table>
<tr><th></th><th>Scan
Map</th><th>Acquire
Capture
Create</th><th>Package
Store</th><th>Share
Transfer
Apply</th><th>Transform
Innovate</th></tr>
<tr><td>Organisation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Group/ Work Team</td><td></td><td></td><td></td><td rowspan="2">• Explicit and tacit knowledge
• During construction stage
• Professionals and operatives</td><td></td></tr>
<tr><td>Individual/ Actor</td><td></td><td></td><td></td><td></td></tr>
</table>

There are two main theories on social networks, firstly social network analysis and secondly social capital theory. In order to decide which one is best to adopt for this study, the following two sections explore both theories in more detail.

4.2.1. Social Network Theory

Research on network structures started as early as 1916 with Fayol (Seufert *et al.,* 1999). The concept was developed out of social theory combined with formal mathematical, statistical and computing methodology (Wasserman and Faust, 1994), allowing not only a mathematical, but also a graphical analysis (Pryke, 2008). Moreno's 1930's invention, the sociogram, marked the beginning of sociometry. However, it was not before 1954, when Barnes first used the term 'social network' (Wasserman, Faust, 1994).

Social network analysis (SNA) provides a conceptual way of thinking about the social world, with a particular interest in the interrelatedness of social units (Wasserman, Faust, 1994). Thus it provides an alternative approach to the assumption of independent social actors, and a framework for testing theories about structured social relationships. The social network theory emphasizes the fact that each individual is never isolated, but connected with others. Schutz (1971; in Granovetter, Swedberg, 2001) describes that each individual is born into a pre-given social world, i.e. a complex social structure, which evolved through history. Thus this affects the motives and actions of each individual and hence should be taken into account. A social network analyst tries to model these relationships in order to illustrate the structure of the so-called 'actor set'. It is then possible to study the impact of this structure on the functioning of the group, and on individuals within the group (Granovetter, Swedberg, 2001). Therefore social network analysts argue that research should always consider this social context (ibid). An entire body of methods has been developed for its analysis (Wasserman, Faust, 1994). Thus the data generated is quite different from the typical one in social and behavioural sciences.

4.2.1.1. Main components of Social Network Analysis

The main components of SNA are:

- Social Network
- Actor
- Relational tie
- Dyad /Triad
- Subgroup / Group
- Density of the Network
- Centrality of an Actor

Wasserman and Faust (1994) define a *social network* as a finite set of actors and the relations between them. Boundaries of networks are difficult to determine, because networks often overlap with each other. Hence the term of 'blurred boundaries' can be used (Seufert *et al.,* 1999). For that reason boundary specification and thus network sampling are important issues in setting-up a research project (Wasserman, Faust, 1994).

Actors are considered as the nodes of a SN and are linked with each other. There are various types of *actors*, e.g. organizations, communities or simply individuals.

Ties represent any kind of existing relationship between actors (Wasserman and Faust, 1994). The collection of ties of a specific kind among members of a group is called *relation* (Wasserman, Faust, 1994). This is also known as the tie content, such as:

- attitudes
- roles
- kinship
- material transactions
- flow of resources
- behavioural interaction
- group memberships
- or as in this study: knowledge

A *dyad* is a unit of analysis and consists of a pair of actors and possible ties between them. Hence a *triad* is a subset of three actors and their possible ties. Since this does not represent a whole network, it applies more to the analysis of a subgroup of an actor set (Pryke, 2008).

A *subgroup* represents any subset of actors and all ties among them. Whereas a *group* is the collection of all actors, on which ties are to be measured. This concept is similar to the so-called actor set. A network can contain only one *actor set*, i.e. a finite set of actors chosen out of conceptual, theoretical or empirical reasons (Wasserman and Faust, 1994).

Network density expresses the total number of links between the nodes of a network. It is calculated by the number of existing ties divided by the number of possible ties (Wasserman, Faust, 2009). The density value lies between 0 and 1.00. A density value of 1.0 means that all nodes are linked to each other in the network, though this is rather unlikely to happen in reality (Pryke, 2008). Nonetheless, Scott (2000) put forward that in a network with directed links it is vital to consider the reciprocity of connections. A directed link from A to B might not necessarily involve a link from B to A.

Actor centrality indicates the number of links of one particular actor to others, in comparison to the possible number of links in that network. A high actor centrality could indicate the importance of this actor regarding the examined relation, i.e. tie content (Pryke, 2008).

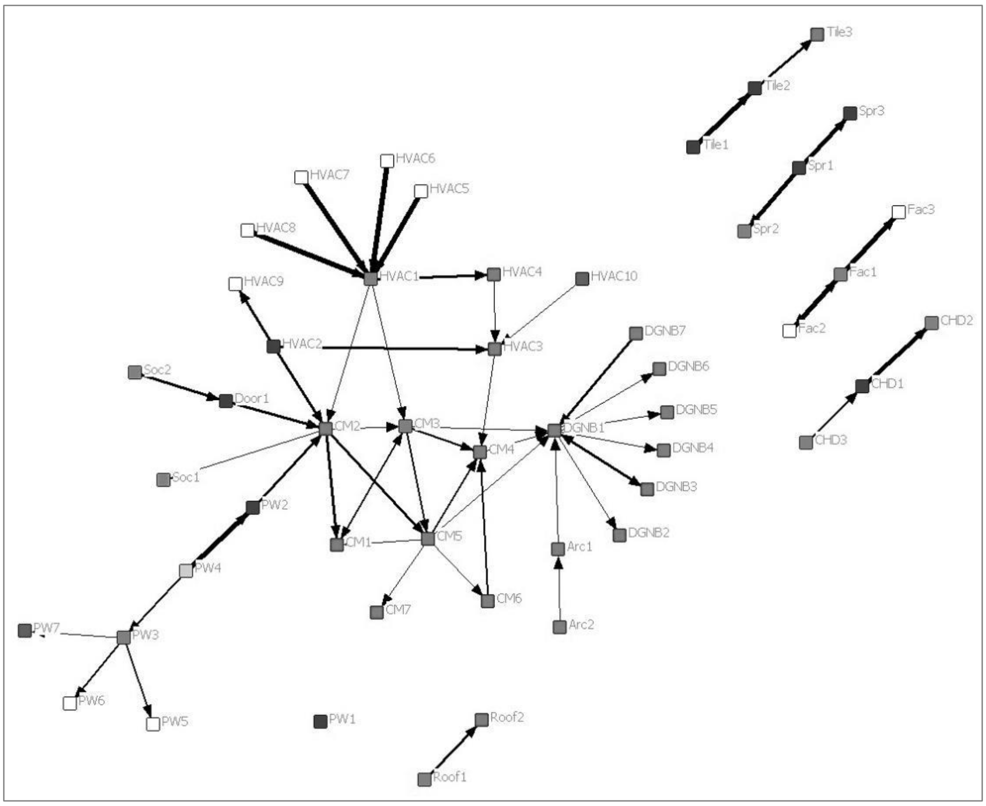


Figure 4.1: Example of a Social Network with various Characteristics

Figure 4.1 presents an example of a social network, as a so-called sociogram. A matrix describing the relationships between various actors can be converted into such a graph (Scott, 2000), by using social network computer programs, such as in this example Netdraw (Borgatti *et al.,* 2002). The nodes represent the various actors of the network. Hence all actors together represent the actor set under examination. The actor PW1 on the bottom is an isolate, as he/she is not connected to any of the other actors. The rest of the actor set is divided into six subgroups or components. The largest subgroup can also be called the main component of the network. Roof1 and Roof2 represent a dyad. The four subgroups on the right hand side are triads. Each actor in the middle of a triad has a high actor centrality in this subgroup. Furthermore the links are directed, i.e. show the exchange direction of the relation under examination, and valued (Hanneman, Riddle, 2005), i.e. possess different line weights to show for instance the frequency of exchange.

Since the tie content, i.e. the relationship under examination, is knowledge, the next section investigates how social network theory can be applied in the context of KT.

4.2.1.2. Social Network Theory and Knowledge Transfer

Inkpen and Tsang (2005) put forward that networks provide access to knowledge, resources, markets and technologies. Transfers of non-material resources are frequently communications between actors, where ties represent e.g. sending or receiving messages, giving or receiving advice, passing on gossip or providing information (Granovetter, 1973). This view is supported by Michaelson (1990; in Wasserman, Faust, 1994) by stating that information about innovations is frequently diffused over such communication channels. Fong (2003) expands on this by arguing that emergent knowledge is generated through various means, including social networks. Language has a direct and important function here as the method used to discuss, exchange information, ask questions and conduct business (Nahapiet, Ghoshal, 1998).

Even, if social relations were established for other purposes, most information channels reduce the amount of time required to gather information (Nahapiet, Ghoshal, 1998). Thus other resources are available through the contacts social networks offer, e.g. through ‘weak ties’ and ‘friends of friends’ (Granovetter, Swedberg, 2001). Network members can gain privileged access to information as well as opportunities. Burt (1992; in Nahapiet, Ghoshal, 1998) expounds by saying that social networks, particularly those characterized by ‘weak ties’ or ‘structural holes’, increase the efficiency of information diffusion through minimizing redundancy.

These personal networks are also overall important for team performance, as Rosenthal (1997) discovered that differences in social networks do explain performance variations. The structure of relationships of team members can enhance or inhibit boundary crossing activities and thus team performance itself (Rosenthal, 1997). However, Roy *et al.* (2003) state that the adoption of new knowledge often means the rejection of past practices with an effect on the economy, culture and social system. Since sustainability brings with it a new body of knowledge (Häkkinen, Belloni, 2011), one has to consider a possible change on these three levels of working life.

Smith (2009) argues that many KM problems are caused by forgetting that individuals are part of the process. This view is also supported by Roy *et al.* (2003), who describe that early organisational KT rather dealt with knowledge as an object, saw the user as a passive actor and completely ignored the context. This can be solved through adopting a SN approach.

Müller-Prothmann (2007) argues that SNA is a very effective tool for analysing KT in networks and can support it by e.g. identification of experts and discovery of improvement opportunities. Hence a SN approach offers the possibility and methods to show the context and map the knowledge flow in a sustainable construction project. This can then be analysed and used to make recommendations. In summary this leads to the assumption that social network theory provides the means for fulfilling the research aim.

4.2.2. Social Capital Theory

An alternative approach to social networks is provided by the so-called 'social capital theory'. This concept was first mentioned by Hanifan in 1916, hence was developed at the same time as SN theory. The first contemporary analysis was produced by Bordieu in 1983. Moreover Portes (1998) names Loury (1977), Coleman (1988) and Burt (1992) as key authors in the area of social capital.

The term 'social capital' refers to the benefits gained by an actor from the fact of being embedded into a social structure (Alguezaui, Filieri, 2010). Thus it is quite similar to SN theory. However, it is argued that the pure existence of this network is neither natural, nor a socially given fact (Bourdieu, 1983). The central proposition is that networks of relationships represent a valuable resource for the conduct of social affairs, providing their members with 'collectively-owned capital' (Nahapiet and Ghoshal, 1998). According to Bourdieu (1983), any form of capital is convertible into economic capital, as capital is accumulated labour in its materialised form. Therefore, if individuals invest into acquiring social capital, they can then convert it into economic one. Bourdieu (1983) argues that capital exists in three fundamental forms:

- economic capital, which is immediately and directly convertible into money
- cultural capital, which is convertible on certain conditions into economic capital and exists e.g. in form of educational qualifications
- social capital, made of social connections

Cultural capital, or so-called 'Bildung' (the German word for education), resides in each individual, thus presupposes embodiment or internalisation. The work of acquiring cultural capital is work on oneself, i.e. self-improvement, thus an effort that presupposes a personal cost (Bourdieu, 1983). This concept is close to Coleman's human capital, as the possible use of educational credentials (1988; in Portes 1998).

Furthermore Bourdieu (1983) defined *social capital* as 'the aggregate of actual or potential resources, linked to the possession of a network with institutionalized relationships of mutual acquaintance or recognition'. This definition reveals two major aspects: firstly social ties enabling the actor to access resources embedded in his/her network, and secondly the quantity and quality of those resources (Portes, 1998). The collectively owned capital in the network provides the actors with security and credit worthiness. Nevertheless, social capital owned by each individual depends very much on the expansion of his/her network, the capital residing in it and the ability to mobilize it (Bourdieu, 1983). Therefore social capital resides in relationships, which are created through exchange (Portes, 1998). Hereby time is an important factor for the development of social capital, since all forms depend on stability and continuity of the social structure. In summary the network is the product of individual and collective investment strategies, which were made deliberately or not, but which will be useful sooner or later (Bourdieu, 1983).

New intellectual capital is created through combination and exchange of existing intellectual resources that may exist in the form of explicit and tacit knowledge, and knowing capability. In this way social capital theory is similar to social network theory. However, social network theory does not see the network as a resource for economic benefit only, but for other resources as well. The following section examines whether social capital theory can be applied to this research in order to enhance KT on sustainable construction.

4.2.2.1. Social Capital Theory and Knowledge Transfer

Nahapiet and Ghoshal (1998) declare three dimensions of social capital as structural, relational and cognitive. The structural and relational dimensions are related to Granovetter's (1992) discussion of embeddedness. Hereby structural embeddedness refers to properties of the social system and the network of relations as a whole. Whereas relational embeddedness describes the kind of personal relationships individuals have developed with each other through previous interactions (ibid). The cognitive dimension refers to those resources providing shared systems of meaning among parties (Cicourel, 1973; in Nahapiet, Ghoshal, 1998). These three dimensions of social capital are shown on the left hand side of Figure 4.2.

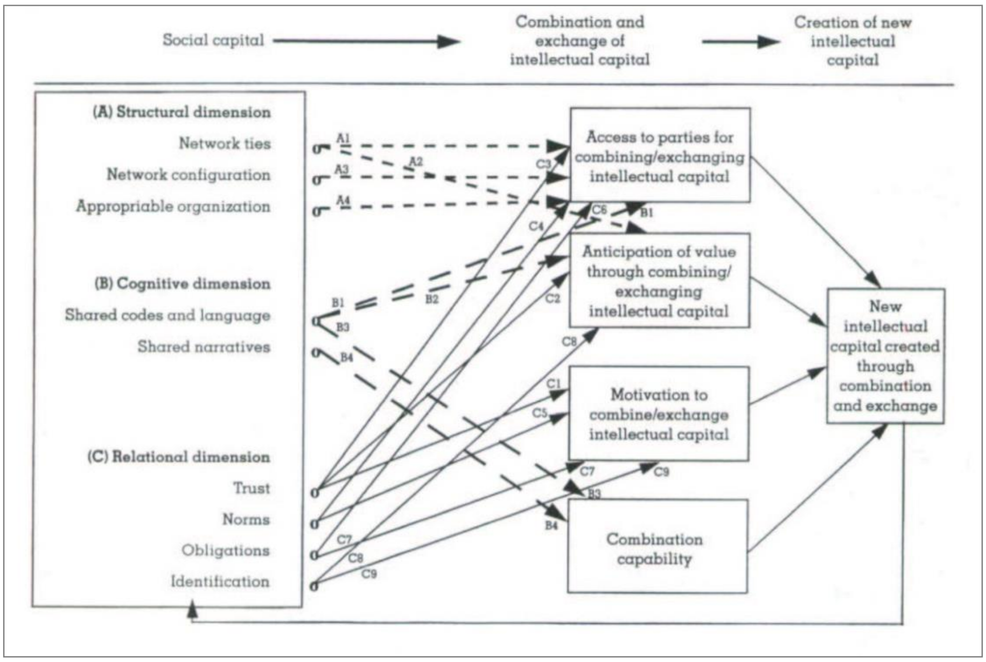


Figure 4.2: Social Capital in the Creation of Intellectual Capital (Nahapiet and Ghoshal, 1998)

Nahapiet and Ghoshal (1998) defined three conditions, to be vital for knowledge exchange to take place:

- opportunity to make the exchange
- parties anticipate the interaction
- motivation for knowledge sharing

While motivation is part of each individual participating in a KT process, anticipation and opportunity could be eased through the use of a social network. Nahapiet and Ghoshal (1998) state that social capital facilitates the development of intellectual capital by affecting the conditions which are necessary for exchange and combination to occur. They argue that the three dimensions of social capital (structural, cognitive and relational) influence four conditions for resource exchange. Thus it follows the fundamental proposition of social capital theory, i.e. network ties provide access to resources (Nahapiet and Ghoshal, 1998).

It has to be considered that in order to gain capital, an on-going investment is necessary in form of working on relationships and thus continually confirm them. This involves investment in form of time, hence money. This investment only makes sense, if each individual has the ability to overlook and use the capital residing in the network (Bourdieu, 1983). The construction sector renders this aspect difficult as it is an environment of temporary multidisciplinary project teams (Kamara *et al.,* 2002). Therefore it is rather demanding to maintain a long-term boundary-spanning network with other disciplines.

4.2.3. Reasoning for adopting Social Network Theory

One of the main distinctions between social capital and social network theory might be the fact that social capital theory regards the social network rather as a conduit for gaining capital, while social network theory puts it in a much wider context. Portes (1998) argues that 'social relationships should be studied in all their complexity rather than examples of a value.' Social networks are a repository for various items, such as friendship, support and advice, without necessarily connecting it with economic capital. Although in the context of this study the transfer of knowledge on how to build sustainably could mean economic benefit for the participating companies in the long run. However, it also involves aiming for a better quality standard of the built environment, which in the end means less carbon emissions of buildings, leading to a better environment for everyone.

Moreover in social capital theory it is argued that each individual has a different, i.e. his/her own, social network. Yet, for research matters it is important to define the boundaries of the examined social network. As this research examines the KT on how to build sustainably inside specific construction projects, each project resembles one social network. Hence the body of methods developed for SN theory makes it more applicable to this study.

Furthermore Pryke (2008) states that SNA offers a detailed way of looking at actor profiles and also consider the context of the project, thus it can provide very rich data. Moreover it is a quantitative method, which can still represent the total complexity of construction industry within an interpretive context. This is especially important as construction projects are unique, and thus repeatability is very limited (Pryke, 2008).

Determining the boundary of the set of actors, allows to describe and to identify the population under study. SNA can help to graphically represent communication structures in the team, using points to depict actors and lines to depict channels of communication (Wasserman, Faust, 1994). These are both important properties of group structures, and properties of individual positions within these structures. Hence SNA is able to show the impact of structural arrangements on, e.g. group problem solving and individual performance (Wasserman, Faust, 1994). Since structures may be behavioural, social, political or economic, SNA offers a flexible set of methods with broad interdisciplinary application (Wasserman and Faust, 1994). Such networks, in which people come from different backgrounds and have numerous perspectives, are described as open-networks (Alguezaui and Filieri, 2010). As argued previously, if one applies SNA to this research, the actor set could be the project participants of one particular sustainable office construction project, i.e. subgroups of individuals from different disciplines/companies. Figure 4.3 illustrates the possible subgroups of a sustainable construction project.

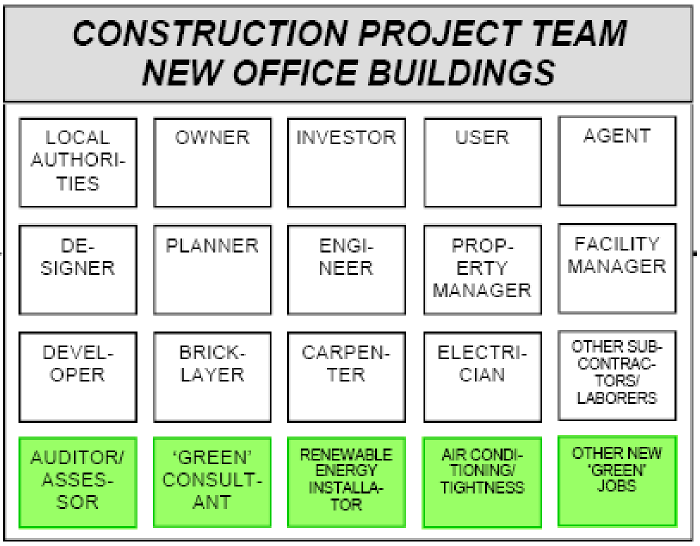


Figure 4.3: Possible Subgroups in a sustainable Office Construction Project, including new 'green' Job Roles

Since limitations of IT-networks for knowledge capture and codification have long been emphasised, the attention has more and more shifted towards the role of social networks in enhancing or inhibiting knowledge transfer (Bresnen *et al.,* 2003). Although there has been considerable research in the area of social networks in general, with a particular emphasis on theoretical models for social network analysis (e.g. Hastings, 1996; Freeman, 2004) in order to analyse mega networks of society, these models have mainly been applied to the manufacturing industry and the economic sector (e.g. Siemieniuch, Sinclair, 1999). Research on social networks within the built environment is limited, even though the main delivery mechanism of the industry is project networks that are formed of a wide-variety of professionals affiliated with a range of companies (e.g. Knight, Ruddock, 2008).

Rohrbacher (2001) suggests that a way to better understand and subsequently overcome barriers to sustainable buildings could be to analyse buildings and involved actors as socio-technical systems, i.e. analyse functional dependencies and requirements, but also their interests, perspectives and interaction. In addition Spinks (2011) argues that the adoption of SNA to the process of sustainable buildings is an appropriate approach as it enables critical analyses of the effects on multiple actors engaging with them. This research project will follow these recommendations and apply social network theory in order to investigate the KT within construction project teams.

The following section explores various social network models on KT and their potential to enhance KT in sustainable construction projects.

4.3. Social Network Models on Knowledge Transfer

Literature exhibits various SN models on KT. The following ones helped identifying various SN characteristics that influence KT, in line with the second research objective presented in Chapter 1.

Borgatti and Cross (2003) found out that seeking information from another person is a function of knowing what that person knows, valuing what that person knows, being able to gain timely access to that person's thinking, and perceiving that seeking information from that person would not be too costly. Furthermore they argue that learned characteristics of relationships affect the decision to seek information from other people (ibid). The sum of these conditions affects the success of the interaction.

The critical challenge in practice is how to provide access to knowledge within and between work communities (Ruddy, 2000), which is also vital for the innovation process (Laursen, Salter, 2006; in Alguezaui, Filieri, 2010). It might not be clear to one person, that someone from a different company and thus different discipline possesses relevant and helpful knowledge. Hence it is important to know that someone else has valuable expertise and this person, thus the knowledge, is also accessible (Borgatti, Cross, 2003). Huang and Newell (2003) examine the dynamics of knowledge integration in the context of cross-functional project teams, focusing on efficiency, scope and flexibility of knowledge integration. The findings confirm that it is basically a process of engaging actors through promotion of project benefits and management of social networks. The organization's embedded practices, past integration experience and social capital were identified as the main important factors.

In addition to this, Fong (2003) explores knowledge creation in multidisciplinary project teams, revealing that these processes are not linear, but interwoven and occurring throughout projects. Figure 4.4 illustrates the four processes of boundary-crossing knowledge creation: knowledge generation, knowledge sharing, knowledge integration and collective project learning. The knowledge sharing process is described as contributing to the integration and generation of knowledge and to the overall learning process. Yet it lists only very few, rather individual actor attributes as contributing factors. Social networks are assigned to knowledge generation and are apparently regarded as a resource only, similar to print sources and not also as the actual place, where knowledge sharing occurs. This seems odd as participants gain access to resources through a sharing process, as for instance stated by Inkpen and Tsang (2005), who put forward that networks provide access not only to resources, but markets, technologies and knowledge of any kind. Hence social networks can be seen as both a resource and the means for KT (Granovetter, 1973).

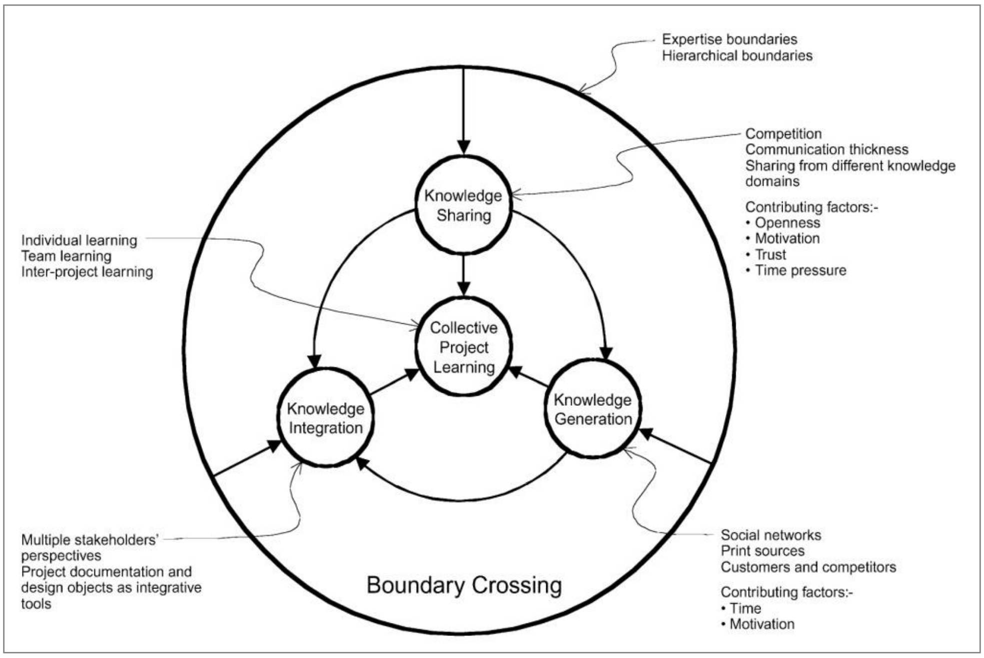


Figure 4.4: The Interrelationships between multidisciplinary Knowledge Creation Processes (Fong 2003)

Bresnen *et al.* (2003) also go along with the proposition of social networks supporting KT, especially in project based environments as the construction industry. The main findings are that processes of knowledge capture, transfer and learning in project environments rely very much on social patterns, practices and processes (ibid). Van Wijk *et al.* (2008) support this view by emphasizing network characteristics as one of the three crucial factors influencing KT, the other two factors being knowledge characteristics and organisational characteristics.

Hansen (2002) explores why some business units are able to benefit from knowledge residing in other parts of a company, while others are not. The focus is on effective interunit knowledge sharing in a multiunit company. This requires a joint consideration of relatedness in knowledge content among business units and a network of lateral interunit relations that enables task units to access related knowledge. The main finding is that projects in divisions with short network path lengths to others that possessed related knowledge, obtained more knowledge and thus were completed faster. This might be due to search benefits accruing to project teams with such a network position. However, neither the extent of available related knowledge in the company, nor the path length in the entire network explained the amount of received knowledge from other divisions and the project completion time (Hansen, 2002).

An alternative approach could be informal employee networks or so-called 'communities of practice', which are an inexpensive and efficient way to share knowledge (McDermott, Archibald, 2010). Similar to teams, communities of practice have goals, deliverables, assigned leadership, and accountability for results. However, they differ from normal work teams as they are responsible for the long term development of a body of knowledge, rather than focusing on a specific deliverable. Moreover so-called community leaders connect members and facilitate discussions, without having authority over members. Communities deliberately seek to expand the internal and external resources and experts available to individuals, compared to consult their colleagues for help with difficult technical problems. While teams rather focus on a given problem, communities manage the knowledge in their domain with the aim of solving problems that have not even been discovered yet (ibid). In summary communities of practice could provide an informal network for transferring knowledge on how to build sustainably within a construction team. Yet, they seem to be very time consuming and difficult to realize regarding the temporary multi-disciplinary project teams in construction industry (Kamara *et al.,* 2002). Nonetheless they could offer an enhancement opportunity for KM in companies.

The aspect of cross-functional teams is especially important in the context of construction industry, as the exchange of information between different disciplines might also lead to misunderstandings, because of a lack of specialised knowledge, forgetting details, failing to mention everything, filtering, or even deliberately withholding certain aspects (Hansen, 2002). In addition, the more intermediaries needed, the higher the chances of such distortion, and hence the less precise is the information that is passed on (ibid). This is vital in a construction project, since participants are from a very diverse range of disciplines (Knight, Ruddock, 2008). However, social networks are recognized as the main drivers for learning and managing knowledge and competencies, especially those lying outside the firm's boundaries (Alguezaui, Filieri, 2010). As a result it is essential to reveal the social network within a construction project and understand its impact on the existing KT between the various actors. This might help suggesting ways of enhancing future KT, especially on how to build sustainably and hence overcome the performance gap.

The previous sections demonstrated that SNs are the conduit for KT. Previous studies have found out that the characteristics of networks affect the extent of transferred knowledge (e.g. Argote, Ingram, 2000). The next section will explore these findings in more depth in order to determine these SN characteristics, in line with the second research objective.

4.4. Social Network Characteristics influencing Knowledge Transfer

In addition to the main components of SNA introduced in section 4.2.1.1, this section explores their potential influence on KT.

4.4.1. Network Structure

Reagans and McEvily (2003) declare that network structure itself affects KT. The main properties of the network structure are:

- Size
- Components
- Connectivity and Cut-points
- Cohesiveness
- Network Range
- Density and Structural Holes

The *size of a network* is simply defined by counting its nodes, i.e. actors under surveillance. KT in smaller networks differs to the one in larger networks, as the network gets larger it is most likely that the density value will decrease (Hanneman, Riddle, 2005).

A *network component* is described by Scott (2000) as a set of actors that are all linked to each other. Hence a graph usually consists of separate components and probably some isolates, i.e. actors not connected to any other actor (ibid). This affects KT as knowledge cannot be transferred between components. Moreover isolates cannot be reached at all. Hence there is no learning, support or influence between isolates and the rest of the network (Hanneman, Riddle, 2005).

The *connectivity* of a network is described by Wasserman and Faust (2009) as whether a network remains connected when lines or nodes are deleted. As a result a *cut-point* is significant in this concept. A cut-point is an actor who connects various network components. Hence its removal results in more components (Scott, 2000). It is important to detect cut-points within a network, as they function as bottlenecks for the knowledge flow (Müller-Prothmann, 2007). A similar effect can be observed for links that function as a so-called bridge between components. Thus its removal results also in more components (Wasserman, Faust, 2009). Brookes *et al.* (2006) confirm that the connectivity of relationships can improve project KM.

Since interpersonal networks play an essential role in the KT process, *social cohesion* and *network range* are important supportive factors. Hereby *social cohesion* is understood as the extent to which a relationship is surrounded by strong third-party connections. *Network range* refers to the extent to which network connections span institutional, organisational or social boundaries (Reagans, McEvily, 2003). As a result both network characteristics affect KT in terms of available knowledge sources.

Network density, i.e. the total number of links between the nodes of a network, does affect KT, as less links, thus a lower density, mean less KT. As explained in section 4.2.1.1 the network density value lies between 0 and 1. A value towards 1 would represent a very dense network with all nodes being linked, while a value towards 0 equals a sparse network. Nonetheless, a dense network is inefficient because it returns less diverse information for the same cost as that of a sparse network (Nahapiet, Ghoshal, 1998), whereas sparse networks may increase the absorptive capacity of a network. Thus most productive teams are internally cohesive, but have external networks full of structural holes (Reagans, McEvily, 2003). *Structural Holes* are parts of the network, where not all possible connections are present. This is more common in larger networks (Hanneman, Riddle, 2005). People at opposite ends of a structural hole might not have much knowledge in common which can impede KT. Nonetheless a strong tie across a structural hole can have a positive effect. An individual surrounded by a diverse network could transfer knowledge across a structural hole, even when the connection is weak (Burt, 1992; in Portes, 1998).

Several scholars argue that cohesive social networks facilitate the transfer of complex and tacit knowledge between individuals (Hansen, 1999; Reagans, McEvily, 2003). Hereby *cohesiveness* refers to the degree of tie redundancy and interconnectedness among network members. A network is described as cohesive when all actors within that network are connected to each other. In a cohesive network members are likely to come up with alternative interpretations to the current problems and develop novel ways to solve these problems (Powell, Smith-Doerr, 1994; in Alguezaui, Filieri, 2010). This was confirmed by Obstfeld (2005; in Alguezaui, Filieri, 2010) for instance, who demonstrated that individuals embedded into cohesive networks are more likely to engage in innovation activities. Table 4.2 summarises benefits and risks of cohesive and sparse networks identified by Alguezaui and Filieri (2010) in the work of Coleman (1988) and Burt (1992).

Table 4.2: Benefits and risks of cohesive and sparse networks (Alguezaui, Filieri, 2010)

	Benefits	**Risks**
Cohesive networks	Effective problem solving Effective sharing of fine-grained information Trust Tacit norms of behaviour Redundant information channels Risk sharing attitude Shared identity Effective collaboration Reduced risks of opportunistic behaviour Reduced transaction costs Easy resource mobilization Shared understanding of problems and solutions Members more likely to engage in innovation activities	Costly relationship maintenance Redundant knowledge flows Restrain firm's capability of exploring new knowledge and exploiting novel recombination 'Not invented here' syndrome 'Lock in' situation
Sparse networks	Access to unique knowledge Control of information exchange Efficient knowledge search Inter-industry knowledge recombination	Action problem Impede frequent interactions Poor understanding of the knowledge (and resources) available

Table 4.2 indicates that cohesive networks are better for effective collaboration, as they provide trust based connections through shared identities and norms of behaviour. Whereas sparse networks provide access to unique knowledge and allow inter-industry knowledge recombination. It can be assumed that in construction projects cohesive networks are within each team, but the overall network structure is probably sparse.

4.4.2. Tie Characteristics

Uzzi (2001) argues that it is not only the network structure that affects KT, but also the embeddedness of ties. Ties are considered to be the links through which KT between actors occurs. Here the quality of a tie, i.e. the relationship and how it is managed, designates e.g. the access opportunities of an actor (ibid). Moreover respect, longevity of a relationship and shared professional and educational backgrounds support KM in project environments (Brookes *et al.,* 2006). Shared cognitive frames are also emphasized by Augier and Vendelø (1999) to ease the transfer of tacit knowledge. Uzzi (2001) put forward that in such relationships the KT is more fine-grained, tacit and holistic than in others, as the motivation for the exchange is more socially-driven than selfish or cooperative.

Granovetter and Swedberg (2001) go along with this by highlighting that tie characteristics between actors in a social network are highly influential in KT. The strength or weakness of a tie determines what type of knowledge is shared. Therefore strong ties, identified by trust, lengthy timeframes and close relationships, are best for sharing tacit knowledge (Augier and Vendelø, 1999), whereas weak ties limit this exchange (Fernie *et al.,* 2003). As a result the transfer of tacit knowledge should be easier between strong ties, because the motivation to assist a contact is greater than in weak ties (Reagans, McEvily, 2003). Nonetheless Granovetter argues that weak ties provide access to novel information (1973). The concept of weak ties is therefore similar to the one of structural holes (Burt, 1992; in Portes, 1998).

McAllister (1995; in Zhou *et al.,* 2009) defined two functions of trust, one is based on cognition and the other one is based on affection. To enhance cognitive-based trust, group members should always be informed of other members' expertise. This way when knowledge is needed, they know which member possesses the required knowledge (Zhou *et al.*, 2009). This concept is similar to the 'transactive memory' by Wegner *et al.* (1991) presented in section 3.4.1.2.

Often acquiring knowledge is risky, because it implies admitting incompetence and dependence. That is why affect-based trust is important in knowledge seeking (Zhou *et al.,* 2009), as it enhances the willingness to expose a lack of knowledge (Borgatti and Cross, 2003), as discussed in section 3.4.1.2. Since trust develops over time, opportunities for KT between individuals should increase (Inkpen, Tsang, 2005). Riege (2005) expands on that by saying that it is mostly in informal networks that people trust each other, voluntarily share knowledge and insights with each other, hence collaborate actively and willingly. This would imply that work environment networks perform worse. However, many people develop friendships with their working colleagues. Hence it is important to identify the relationship actors have with others in the network, especially with those who they usually share knowledge with, as this could provide further explanations on KT.

Ties can be distinguished into e.g. instrumental and expressive ties (Podolny, Baron, 1997; in Zhou *et al.,* 2009). While instrumental ties arise from formal work roles (Ibarra, Andrews, 1993; in Zhou *et al.,* 2009), expressive ties are more informal, e.g. friendship or social support (Ibarra, 1992; in Zhou *et al.,* 2009). In a working environment each individual has multiplex relationships, thus instrumental and expressive ties often overlap (ibid). Moreover expressive ties tend to link people of the same gender, culture or race (ibid), and lead to similar views on their job and organization (Gibbons, 2004; in Zhou *et al.,* 2009). This aspect is especially interesting, as the previous chapter identified so-called 'general actor attributes', such as gender and nationality, which influence KT. As a result these factors seem to be similar to the social network characteristics influencing KT.

As previously argued in Chapter 3 the differing types of knowledge, e.g. tacit and explicit, are also transferred differently. The interesting point to make here is that even when using social networks, tacit knowledge does not simply diffuse across a network like explicit, the process is more active. Therefore tacit knowledge is, as previously argued, more difficult to transfer and thus needs greater effort and more time. Moreover it is important to also have lateral linkages among subunits for effective KT to occur (Hansen, 2002). Egbu (2004) puts forward that KM that focuses on creating network structures to transfer only explicit knowledge will be severely limited in terms of its contribution to innovation and project success. As previously stated this research focuses more on the KT of tacit knowledge, as it can be assumed that explicit knowledge is generally easier to transfer.

4.4.3. Actor Attributes

Following are examples of actor attributes found in social network and knowledge transfer combined literature. The *general actor attributes* identified and described in section 3.4.2 seem to also apply to the social network perspective of KT and were thus confirmed: nationality, gender, age and hierarchy. Moreover the importance of *access* to the knowledge source and the *transactive memory*, in terms of knowing who knows what were also confirmed through SN literature.

The *cooperative norms* also play an important role in knowledge transfer, as the sender of knowledge assumes that, if they share knowledge with somebody now, someone else will be willing to do the same for them in the future (Reagans, McEvily, 2003). For that reason the sender's reputation within the network seems to be vital. Otherwise news of uncooperative behaviour will spread through the network rapidly and limit their ability to interact with others in the future (Reagans, McEvily, 2003). This approach is similar to the one argued by Wilkesmann *et al.* (2009), presented in section 3.4.1.3

The competitive advantage is no longer based on how much you own, it is about how much you know and how you use it (Ruddy, 2000). Nahapiet and Ghoshal (1998) state that team work and cooperation play a significant role, rather than competition. The group identification may not only increase the perceived opportunities for exchange, but also enhance the actual frequency of cooperation (Nahapiet, Ghoshal, 1998). A competitor on one project may become a partner on another (Seufert *et al.,* 1999). Nonetheless, if strong ties are absent, particularly in alliances between competitors, partners may not develop the necessary relationships for deliberate KT (Inkpen, Tsang, 2005).

The *actor centrality* also seems to influence KT. Wasserman and Faust (2009) describe central actors as the most active ones in the network, as they have the most ties to other actors. Hence these central actors should be recognized by other actors as a major channel for information (ibid). There are four different centrality values to consider. *Degree centrality* shows the average degree of which relations are focused around one or a few central network members. The degree centrality measures are divided into in-degree and out-degree. The in-degree of an actor is the total number of other nodes which have ties towards it, while the out-degree is the total number of other nodes to which it directs ties (Scott, 2003). Actors with more ties are in advantage positions, as they have alternative ways to access resources (Hanneman, Riddle, 2005). *Closeness centrality* describes the integration or isolation of network members. Hence it is based on the sum of the distances from each actor to all the others. Hanneman and Riddle (2005) state that closeness centrality can be misleading in larger and more complex networks. Therefore they recommend the *Eigenvector centrality* to identify the most central actors in terms of the overall network structure. In addition *betweenness centrality* identifies the so-called broker or gatekeeper. This concept was defined by Freeman (1979; in Scott, 2000). The overall betweenness of an actor measures the extent to which an actor lies between other actors in the social network. Scott (2000) put forward that the betweenness centrality is probably the most complex calculation for actor centrality. The concept bases on dependency, as other actors depend on the so-called broker or gatekeeper to transfer knowledge. Thus the concept of betweenness centrality is similar to the one of structural holes by Burt (1992; in Scott, 2000), as the actors on opposite sides of a structural hole could also be called gatekeepers.

Furthermore Müller-Prothmann (2007) defines four different actor roles as crucial for KT, when analysing SNA data. Hence it is important to identify these actors within each network:

- Experts, possessing specific knowledge and experience on the subject area with a central position and a high number of external links.
- Gatekeepers know ‘who knows what’ and build bridges between different subgroups and additionally transfer requested expert knowledge. They are identified through the betweenness centrality as mentioned above.

- Knowledge consumers ask for knowledge and have a rather peripheral network position.
- Contact persons, who provide contacts with experts without actively transferring the knowledge themselves. They have an intermediate position between the experts and the knowledge consumers. These are difficult to detect in this research project due to the nature of questions in the survey. Respondents did not indicate whether someone provided them with a contact to a knowledge source, or the actual required knowledge.

4.5. Conclusion

This chapter has shown how to approach KT from a social network perspective. This was done by reviewing and discussing literature on social networks combined with KT. Social capital theory was debated as an alternative approach towards networks. However, in the end SN theory was chosen for this study, due to the more appropriate methods and the wider perspective of networks as a resource for more than economic benefit. As a result it can be assumed that social networks offer a possibility to enhance KT on how to build sustainably. Moreover they provide the means to map the knowledge flow inside a construction project team for a better analysis of the current KT practices. This then allows making recommendations on how to enhance the KT on building sustainably.

Various social network models and concepts combined with KT were presented and discussed in terms of their applicability to the problem statement. The concepts drew attention to numerous factors which influence KT. The chapter concluded by identifying these influencing social network characteristics, in line with the second research objective presented in Chapter 1. These characteristics were categorised into four groups. This eased the development of the conceptual framework of this study, in line with the third research objective. The conceptual framework will be presented in the following chapter.

The four categories of KT influencing social network characteristics were determined as:

- Network Structure (e.g. Density, Connectivity, Hierarchy, Structural Holes)
- Tie characteristics (e.g. Strength, Weakness)
- Actor Attributes (e.g. Centrality)
- Tie content

The following chapter presents the research methodology and methods.

CHAPTER 5

METHODODLOGY AND METHODS

5.1. Introduction

The previous three chapters established the overall theoretical background and context of this study. This chapter presents the adopted methodology and methods and is divided into five sections. It begins with outlining two different epistemologies, i.e. grounded theory and pragmatism, and discusses their relevance to the problem area. Thereafter the conceptual framework is explained. The third part introduces the case study design and sampling strategy. This is followed by the chosen data collection methods. The chapter concludes by describing how the data was analysed.

5.2. Research Philosophy

There are two main epistemological approaches to research which are closely linked to the methods applied, positivism and interpretivism.

Positivism derives from the natural sciences and hence uses mainly quantitative methods. From a positivist perspective, there is only one reality about the world and what we know about it, i.e. what is observable. A positivist researcher is supposed to be a neutral observer aiming to develop laws and generalisations out of the research results (Bryman, 2008).

Interpretivism has its origins in social science and is linked to mainly qualitative methods. From an interpretivist perspective, there exist multiple truths which are all made by people. As a result qualitative methods are more applicable to develop a deeper understanding of the context. Thus value-freedom is not possible and the researcher should accept a certain level of subjectivity (ibid).

> *'The construction management research community has an interesting history when it comes to debating the merits and demerits of different theoretical and philosophical perspectives on methodologies from different research paradigms. Concerns at the apparent dominance of positivism and the role of theory in construction management research in the mid-1990s led to a philosophical debate in the journal Construction Management and Economics. […] suggesting that the culture of research must change, if researchers were to have an influence on the industry.' (Dainty, 2008 p 1)*

Due to this apparent dominance of especially positivism in construction management research there seems to be a need to change research culture in order to influence industry. As a result it was considered necessary to explore an alternative epistemology and its relevance to the problem area of this study. Pragmatism was chosen, as it is most likely to offer the opportunity to influence the way construction industry conducts its business.

5.2.1. Pragmatism

‘Pragmatism is a word we commonly use to describe a particular way of addressing and resolving issues, a way of acting’ (Ormerod, 2006). Pragmatism was developed during the end of the nineteenth century in the United States with several philosophers being involved, who all contributed a different definition to it. Thus pragmatism is not a dogmatic approach, but is rather universally applicable by many scholars and to many situations. Emile Durkheim for instance, who is rather known as a positivist, was very enthusiastic about pragmatism and even gave a lecture about it in the academic year 1913/14 (Durkheim, 1983).

James, Peirce and Dewey are the most important founders of pragmatism. William James (1842-1910) describes pragmatism as focusing on the outcome of an action rather than on a priori reasons, principles or categories. ‘The pragmatist turns away from verbal solution and towards facts and action’ (James, 1907; in Ormerod, 2006). For Peirce (1839-1914) pragmatism is a philosophy with concepts, which have a meaning through the application in the real world. The experimental conditions of applying these concepts create observable results (Ormerod, 2006). This view is supported by Dewey (1859-1952), who regards knowledge as an ‘instrument for action rather than an object of disinterested belief’ (Ormerod, 2006).

Nahser (1997) explains Peirce’s pragmatic method, as to first ‘perceive what is going on. What is important is not what we think we know, but what we are willing to learn. Then the knowledge and understanding are best acquired in a mutually reinforcing communication with others.’ This ‘abduction’ can be described as the middle way between induction and deduction. The best way of seeking ‘the truth we do not yet know is through survey the evidence, develop hypothesis, and keep on going around this circuit until a discovery or conclusion explains the evidence emerges’ (Nahser, 1997).

Interestingly, regarding qualitative research, there is hardly ever a notice of the pragmatism movement in early research methods literature, which could derive from the assumption that ‘mainstream analytic philosophers tended to ignore pragmatism until the 1980s’ (McDermid, 2006). Since pragmatism was developed in the United States, criticism towards it came mostly from Europe. It has been said that pragmatism resembles the characteristic American social attitudes, such as 'crass materialism' and 'naïve democratisism'. Pragmatism was rather seen as a philosophical expression of populism compared to the 'long-established ideological tendencies of European philosophy' (Ormerod, 2006). Another demerit of pragmatism and also one of the most controversial ones, was articulated by Raitt (1979; in Ormerod, 2006), who declares that 'we do not ask, if it is true, only if it works – we validate not verify.' However, the question remains whether it is better to verify or to validate, and whether validation is a kind of verification.

5.2.2. Adopting Pragmatism

The question of which research philosophy to adopt in this study, was guided by the aim and objectives stated in section 1.3. Thus this study followed Nahser's (1997) description as to first gain an understanding for the current situation, regarding barriers towards sustainable construction on a theoretical basis through a thorough literature review. Thereafter a conceptual framework was developed and tested in practice. From a pragmatist's point of view, this framework mainly has a meaning through the application in the real world (Ormerod, 2006), in this case construction industry. Therefore this research adopts the pragmatism approach through combining induction and deduction.

The pragmatist's approach of this research is meant to have a positive effect for the project teams involved in this study, as they might apply the results of this study to future projects. After all, the main intention of this research is to not only contribute to knowledge, but also to practice, or as Huxley (in Davenport and Prusak, 1998) argued 'the great end of knowledge is not knowledge but action.' As a result pragmatism seems to offer the most possible impact on the way construction industry conducts its business through the applicability of the results to practice.

While pragmatism has found its way into various design disciplines, it is the adoption of pragmatism in urban planning, architecture, and information technology, where it appears to have the most impact (Melles, 2008). Norton (2007; in Melles, 2008) states that there is a special need for pragmatic problem solving within the environmental planning process, which addresses sustainability issues. He criticises that there is no universally applicable problem formulation and solution in environmental policy. Whereas Guy and Moore (2007; in Melles, 2008) declare that there is an observable pluralistic approach encouraged by pragmatism within the process of architectural concepts. Consequently this could be advantageous, when applied to the field of sustainable construction.

An interesting point in the pragmatism movement is that the most realistic basis for decision making is seen in the individual action and experience in the world. Melles (2008) put forward that so-called theory-practice knowledge can develop within this action orientated environment. This ‘experience and theory-practice knowledge’ is a way to handle knowledge and explains the learning process, thus the internalization of knowledge (Melles, 2008). This indicates that a pragmatists’ approach could not only offer a methodological framework for this study, but also suggests a different point of view on KT itself.

However, pragmatism underlines the changing nature of results and with this science itself. After every application to practice, a theory might change again, leaving the findings fallible and not universally valid (Ormerod, 2006). By adopting pragmatism one has to accept the changing nature of results and that they might not be universally valid, as Ormerod (2006) states above. However, this simply means that we have to accept this and thus the results could rather be seen as an improvement suggestion to the construction process.

The next section presents the conceptual framework which was developed in due course of this research project, in line with the third research objective.

5.3. Conceptual Framework

Figure 5.1 depicts the conceptual framework. This model is based on findings of the KT process and its influencing factors, as well as influencing social network characteristics. These findings are discussed in Chapter 3 and 4 and are summarized in Table 5.1. The conceptual framework was tested in practice through case study data which is presented in Chapter 6 and 7. The revised version of the conceptual framework can be seen in Chapter 8.

The conceptual framework is divided in three sections: knowledge input, KT process and possible output. Therefore this section is organised accordingly.

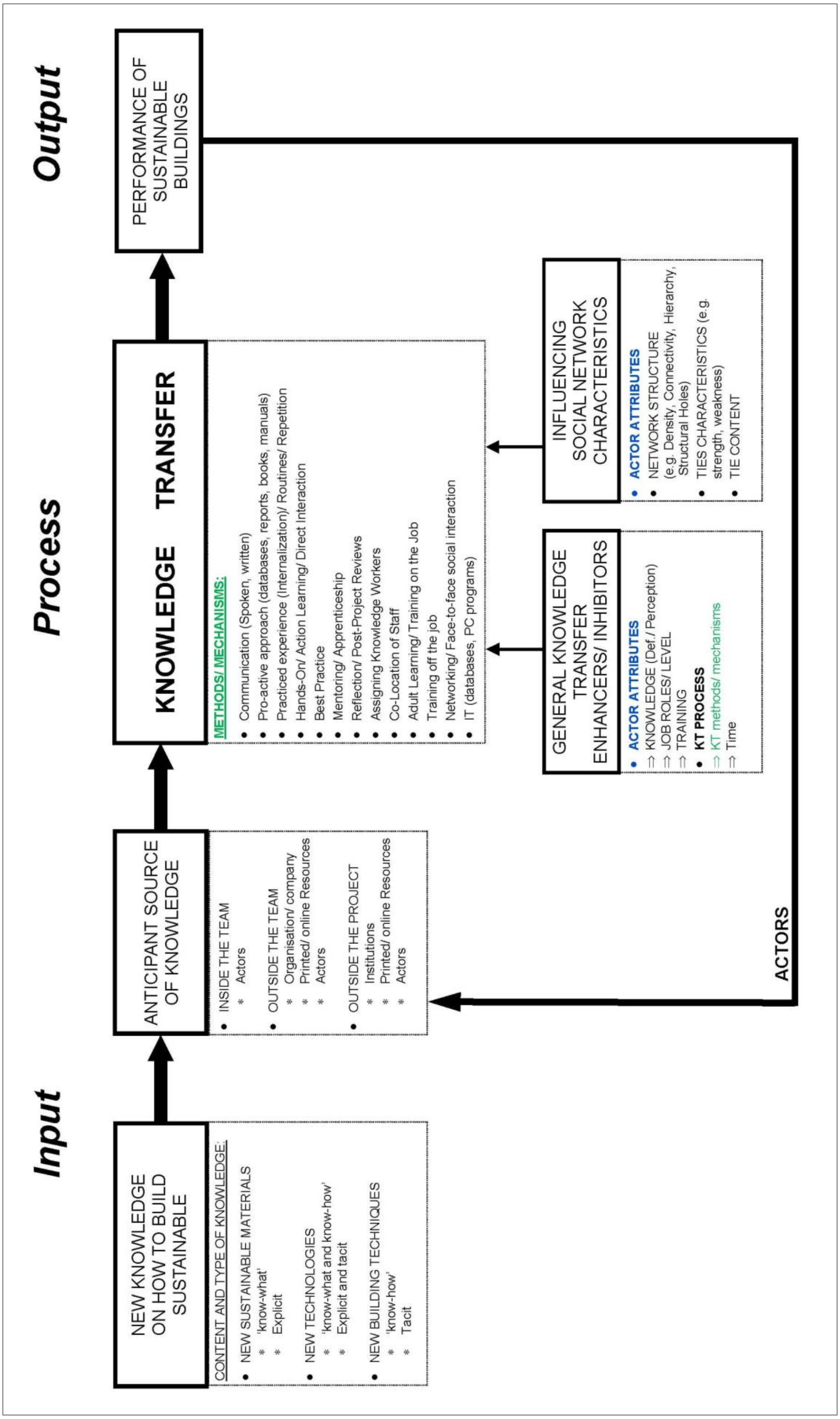

Input
Process
Output
NEW KNOWLEDGE ON HOW TO BUILD SUSTAINABLE
CONTENT AND TYPE OF KNOWLEDGE:
• NEW SUSTAINABLE MATERIALS
* 'know-what'
* Explicit
• NEW TECHNOLOGIES
* 'know-what and know-how'
* Explicit and tacit
• NEW BUILDING TECHNIQUES
* 'know-how'
* Tacit
ANTICIPANT SOURCE OF KNOWLEDGE
• INSIDE THE TEAM
* Actors
• OUTSIDE THE TEAM
* Organisation/ company
* Printed/ online Resources
* Actors
• OUTSIDE THE PROJECT
* Institutions
* Printed/ online Resources
* Actors
KNOWLEDGE TRANSFER
METHODS/ MECHANISMS:
• Communication (Spoken, written)
• Pro-active approach (databases, reports, books, manuals)
• Practiced experience (Internalization)/ Routines/ Repetition
• Hands-On/ Action Learning/ Direct Interaction
• Best Practice
• Mentoring/ Apprenticeship
• Reflection/ Post-Project Reviews
• Assigning Knowledge Workers
• Co-Location of Staff
• Adult Learning/ Training on the Job
• Training off the job
• Networking/ Face-to-face social interaction
• IT (databases, PC programs)
GENERAL KNOWLEDGE TRANSFER ENHANCERS/ INHIBITORS
• ACTOR ATTRIBUTES
⇒ KNOWLEDGE (Def./ Perception)
⇒ JOB ROLES/ LEVEL
⇒ TRAINING
• KT PROCESS
⇒ KT methods/ mechanisms
⇒ Time
INFLUENCING SOCIAL NETWORK CHARACTERISTICS
• ACTOR ATTRIBUTES
• NETWORK STRUCTURE (e.g. Density, Connectivity, Hierarchy, Structural Holes)
• TIES CHARACTERISTICS (e.g. strength, weakness)
• TIE CONTENT
PERFORMANCE OF SUSTAINABLE BUILDINGS
ACTORS

Figure 5.1: The Conceptual Framework

5.3.1. Knowledge Input

The input section of the conceptual framework is divided into two parts. First the definition of subject areas and knowledge types regarding sustainable construction is provided, as argued in section 3.2. Secondly the anticipant sources of this knowledge are presented, as determined in section 3.4.1.

Three different subject areas of this so-called 'new knowledge' on how to build sustainably were identified as materials, technologies and techniques. Different knowledge types, such as tacit or explicit and know-how and know-what were allocated to these subject areas.

Materials include all kinds of new sustainable building materials, such as hemp insulation or triple-glazing windows. The knowledge on these materials is mainly explicit, thus the information on them can be stored and accessed in e.g. databases, manuals, books or the internet. Hence the transfer of knowledge on this subject area is rather easily manageable.

Technologies include e.g. solar panels, heat pumps or rain water harvesting systems. The knowledge type on technologies can be described as a combination of explicit and tacit. The explicit part, i.e. information on these technologies can be stored in for instance instruction manuals or reports. However, tacit knowledge, i.e. know-how is necessary for assembling these systems correctly into a building. Hence it is argued that technologies require a combination of both knowledge types. Thus the transfer of knowledge on technologies is considered to be more intricate than the one on materials.

Techniques stand for 'know-how' on how to put sustainable design intent into a good quality built result. This means any new ways of building with conventional or new materials, or technologies and their correct installation. This is purely tacit knowledge and consequently rather difficult to transfer.

After determining this new knowledge on how to build sustainably, the anticipant source, i.e. where to find the required knowledge has to be identified. As argued in section 3.4.1 knowledge can reside inside and outside of the immediate work team. The expression team corresponds to employees of one participating company, i.e. trade in one specific construction project. Moreover the required knowledge can be found outside the immediate team, i.e. within the rest of the company the team belongs to, or within other teams working on the same construction project. In addition to this the knowledge can also reside outside of this particular project. Either way the knowledge can reside, e.g. in other individuals, i.e. actors, or especially regarding explicit knowledge in printed or online repositories. As previously mentioned individuals are called actors in accordance with SNA literature.

5.3.2. Knowledge Transfer Process and Influencing Factors

As previously argued the KT process is often treated in literature more or less as a black box (Berends, 2005). The conceptual framework exhibits in this ‘box’ several examples for mechanisms and methods of transferring knowledge, in particular tacit knowledge. As explicit knowledge is easier to store and transfer the focus of this study lies on the more difficult transfer of tacit knowledge. This assumes that, if one understands and manages the mechanisms of tacit KT, the transfer of explicit knowledge is easily manageable. All mechanisms and methods were drawn from literature, as presented in section 3.4.2.

In line with the second research objective presented in Chapter 1, various factors influencing the KT process, were identified and allocated to the KT process in the conceptual framework. There are two main groups of influencing factors. First the so-called ‘general KT enhancers and inhibitors’ as presented in section 3.4.2.5, and secondly the influencing SN characteristics as identified in section 4.4. Table 5.1 summarises the results.

Table 5.1: The conceptual framework – Categories of KT influencing factors

	Category	**Description**
General KT enhancers and inhibitors	*Actor Attributes*	i.e. individual personal characteristics of the various participants of each knowledge transfer, such as age, gender, nationality, educational background
	Knowledge	i.e. each actor's own definition and perception of his/her own knowledge, as well as of the required knowledge
	Job Roles/ Level	e.g. in organisation/ company, group/ team
	Training	i.e. inside and outside the company; of- or on-the-job
	KT Process	i.e. methods and mechanisms used during the knowledge transfer process
	Time	Duration of the KT and e.g. time constraints regarding the tight schedule
Social Network Characteristics	Actor Attributes	See above
	Network structure	e.g. density, connectivity, hierarchy, structural holes
	Tie characteristics	e.g. strength, weakness
	Tie content	What is being transferred? i.e. knowledge on how to build sustainably

5.3.3. Output

As previously stated practitioners in the field can use the framework to support KT on sustainable construction which could contribute to the standard of sustainable building quality.

5.4. Multiple Case Study Approach

Among the growing knowledge management literature, case study approaches have been widely adopted (Jenner, 2005; in Ragsdell, 2009), probably in order to undertake an intensive and detailed examination of the whole complexity (Bryman, 2008). Yin (2014) puts forward three reasons when to prefer case study as a method: Firstly, if the research question is a 'how' or 'why' question; secondly, if the researcher has little control over behavioural events; and thirdly, if the focus of the study is rather contemporary. All three points apply to this study, as stated in section 1.3. Moreover, Yin (1994) states that case studies allow the retention of holistic and meaningful characteristics of real-life events within the context of organizational and managerial processes. However, it has to be considered that one main criticism towards case study design is how to generalise from a single case (Yin, 2014)? Yet, a comparative research design with two or more cases could provide a better understanding and validation of the results (Bryman, 2008). Therefore a multiple case study approach was used. As argued previously this study compares the KT in construction project teams trying to achieve a comparable high score in BREEAM or DGNB. Each construction project resembles one case study with the focus of research on the KT in the whole project. Hence a holistic design was applied.

The use of theory to generalize from case studies is called *analytic generalization* by Yin (2014). This is in contrast to *statistical generalization* made on the basis of empirical data. A common mistake is to assume that *statistical generalization* is the way to draw theories from case study results, as the sample size is usually too small to represent any larger population. Instead with *analytic generalization* the results could be used to either confirm, reject or modify theories that were used for the initial design of the case study, or new concepts could be developed out of them (ibid). In this study *analytic generalization* was applied in terms of using case study data to revise the initial design of the conceptual framework, introduced in section 5.3. The revised framework is presented in section 8.3.1.

A case study may involve the use of quantitative and qualitative research methods. It has been argued that qualitative data is the best approach to depict the complexity and uniqueness of construction industry, since the lack of repeatability renders construction projects to be unique (Pryke, 2008). Nevertheless, due to the complex network of relationships, which shape construction industry (Dainty, 2008) a multi-method approach was regarded as necessary. Hence the data collected during this study is a combination of qualitative and quantitative data. When comparing case studies, the level of analysis is first on each case study itself, followed by comparing rather general processes and understandings, than elements (Ragin, 1998; in Schweber, 2013).

This research seeks to compare KT within project teams involved in sustainable office construction projects in the UK and Germany. As argued in section 2.4.1 these are two leading countries in sustainable principles and comparable in size and level of sustainable construction volume. Comparing two different countries renders the multiple case study approach to be cross-cultural and cross-national (Harkness, 2008). Harkness (2008) puts forward that comparative research differs widely from a non-comparative one. For instance, strategies to get a high response rate differ between various cultures. While it might enhance the response rate in the UK to contact companies via telephone, Blohm and Koch (2004; in Harkness, 2008) found out, that it has the opposite effect in Germany. Moreover the socio-cultural context, i.e. race, ethnicity, religion, education, occupation, affects how questions are perceived and whether information is considered as relevant or not

(Harkness, 2008). As a result the so-called 'general actor attributes' identified in section 3.4, gain even more importance in this context.

5.4.1. Case Study Selection

The case study selection turned out to be the most challenging part of this research, as it was rather difficult to get access to suitable construction projects. Section 9.4 - Limitations elaborates more on this issue. The following selection criteria were developed in order to select construction projects with comparable features:

- In order to ensure similarity in the scope of the construction projects, buildings were chosen, with a comparable type, i.e. offices. It was argued in section 2.3 that most research focuses more on residential buildings, although commercial buildings emit similar amounts of CO2. Moreover, offices represent the largest sub-sector of commercial buildings in most countries regarding floor space and energy use (WBCSD, 2009). Besides research has shown that investors do believe that offices are the property sector, which will encounter the most impact from sustainability issues (Keeping, Rawstron, 2010).
- Moreover projects were chosen, which aimed for similar and thus comparable levels of sustainability certificates, i.e. BREEAM or DGNB.
- Furthermore the projects chosen were all new construction, as this enabled a better comparability of the sustainability levels.
- In addition the projects had a similar time frame in order to allow data collection during construction stage.
- Eventually feasibility and access, i.e. participating companies were willing to let this project act as a case study.

A summary of these selection criteria and key features of the studied projects can be found in Table 5.2.

Table 5.2: Case study Selection Criteria

	Case Study I UK	Case Study II UK	Case Study I Germany	Case Study II Germany	Case Study III Germany
Location	London	London	Southwest	Hamburg	North
Project time frame	Completed in March 2012	2012-2014	Completed in November 2011	2011-2013	2011-2014
Gross Area	Ca. 80,000 sq m	Ca. 51,097 sq m	3,692 sq m	22,710 sq m	19,817 sq m
Sustainability Certificate	BREEAM offices 2006	BREEAM offices 2008	DGNB offices 2009	DGNB offices 2009	DGNB offices 2009
Achieved Rating	Excellent (73.2%)	Excellent (71.6%)	Gold (83%)	Gold (81.6%)	Gold (81.7%)
Building Type	Mixed use: office, retail & residential	Office	Office	Office	Office
New or Refurbishment	Partially new	new	new	new	new

5.4.2. Sampling

Naoum (2006) states that *sample* is a part of the whole population, which represents the characteristics of the rest. The process of selecting the sample is considered to be very important and should be carried out with great care (ibid). The sampling was carried out in two stages. The first stage involved sampling the primary unit (Fowler, 2009), i.e. the construction projects. Hereby each case study represents the *sample frame*, as the set of people that have a chance to be selected for the survey (Fowler, 2009). Out of a variety of sampling designs found in literature, the *non-random* design was chosen for this research project in order to decide on the case studies, as each project approached by the researcher fulfilled the selection criteria, described in the previous section.

The case studies in Germany were selected through cooperation with the certifying organisation DGNB. First a list of all new office constructions in Germany with the appropriate pre-certificate was generated from their official website (www.dgnb.de), including the information shown in Table 5.2. This reduced the sample size to 29 projects, as not all projects fulfilled the sampling criteria, e.g. were under construction in the relevant time of data collection. Subsequently the auditors, i.e. assessors, of all remaining projects were contacted and asked, if the project is available for research purposes. In total this involved 272 emails, 17 phone calls and ten meetings in order to explain the research and field work process in more detail. Thereafter the auditor initiated the contact with the developer orowner who gave their consent or not. Nevertheless, only three projects agreed to participate in this study.

The case studies in the UK were intended to be selected the same way, i.e. through contacting BRE and requesting a list of new office constructions aiming for BREEAM certificates and being currently under construction. Unfortunately there was no up-to-date list available, which was caused by a general lack of transparency of BREEAM projects in the UK. A list of supposedly all new office constructions in the UK being under construction was retrieved from the official database of the BRE (www.greenbooklive.com). This list showed 156 on-going new office projects aiming for a BREEAM certificate. Unfortunately this list contained 59 double entries, which left 97 projects. Out of these 97 projects 56 were already finished, which left only 41 projects. These 41 projects were contacted through their assessors and asked, if the project is available for research purposes. Although some assessors were interested in the research results, none of them wanted to participate. As a result of the encountered problems, various developers and assessors of projects discussed in press were contacted through personal and university staff contacts in order to investigate the accessibility for research purposes.

This sampling approach resulted in the five case studies, i.e. two for the UK and three for Germany.. As previously mentioned, section 9.4 - Limitations, further explores the difficulties encountered in finding case studies and the reasons for refusal.

Once each construction project agreed on taking part in this research project, the second sampling stage, i.e. survey administration was carried out in form of a *random sampling* (Fowler, 2009). Hence the researcher visited construction site and randomly handed out questionnaires to the participants on-site at that moment. Yet, it is vital to point out that the quality and quantity of the collected data per case study very much depended on the stage the construction project was in at the time of data collection. Although the researcher of course tried to get a high response rate from all trades involved, it was difficult to get responses from trades that for instance already completed their work. Moreover the project stage itself might have influenced the replies of the participants. This aspect might have biased the results. Nevertheless, Fowler (2009) argues that there is no statistical evidence of how well or poorly the sample represents the population, if the respondent availability affects the chances of selection.

The *response rate* is defined as a parameter to evaluate the data collection effort and success. It is calculated by dividing the number of completed questionnaires by the number of individuals sampled (Fowler, 2009). The response rate of this research is shown in Table 5.3. Fowler (2009) puts forward that there is no agreed-upon minimum of an acceptable response rate in literature. However, as this is not a purely quantitative study the figures are rather meant to get an impression of the amount of collected data. As Table 5.3 indicates, case study GE1 has the lowest response rate with 30%. This is because the project was already completed at the time of data collection, i.e. questionnaires were only administered via emails. The high response rates in case studies UK1 and GE2 were achieved through great management support.

Table 5.3: Key features of studied cases

	Case Study UK1	**Case Study UK2**	**Case Study GE1**	**Case Study GE2**	**Case Study GE3**
Period of data collection	02.12.2011 - 17.12.2011	06.07.2012 – 17.07.2012	23.02.2012 – 24.05.2012	19.09.2012 – 19.11.2012	24.09.2012 – 06.12.2012
Number of companies taking part in research	15	4	6	11	6
Number administered questionnaires	45	30	20	25	25
Number of completed questionnaires	39	11	6	22	11
Response rate	86.6%	36.6%	30%	88%	44%

5.5. Research Methods

5.5.1. Literature Sources

The literature review was essential in order to form the basis of the study and to provide a background for the gap in knowledge. Naoum (2006) states that a literature review should be carried out in order to demonstrate an understanding of existing knowledge in the subject area, to identify central issues and build bridges between them in order to fill the gap in knowledge. This has been demonstrated in Chapter 2, 3 and 4, covering the three main areas of this study: sustainability in the built environment, knowledge management and social network theory. Furthermore the conceptual framework was developed out of the literature in line with the research objectives stated in Chapter 1. Additionally the literature review helped with choosing the appropriate methodology and methods used in this research. The literature review was updated until May 2013.

5.5.2. Survey Research

There are four main reasons for using surveys in this research.

Firstly questionnaires are the commonly used tool to collect social network data (Wassermann and Faust, 2009), which is necessary to map the knowledge flow in construction project teams.

Secondly questionnaires are obviously a more efficient tool to observe a lager sample in a shorter amount of time, compared to e.g. interviews (Nardi, 2006).

Thirdly another advantage of survey research is that the outcome is more reliable than the one of more qualitative methods, through a standardised way of asking questions (Nardi, 2006; Schwarz *et al.,* 2008). For instance, in interviews the researcher does not formulate the same question in exactly the same way to all interviewees. Hence, the same question could be understood, interpreted and thus answered in different ways. This is very unlikely to happen with questionnaires, as the questions are formulated the same for everyone.

Fourthly, while exploring knowledge issues, it might be difficult for participants to admit that they do not entirely possess the expertise to fulfil the jobs they have been employed for. Nonetheless, it might be easier for respondents to admit some lack of knowledge on a sheet of paper, compared to a personal interview.

A possible disadvantage of questionnaires is the lack of contextual data. Yet, it was tried to overcome this by including open questions, as described in section 5.5.2.2 – questionnaire design. In summary this led to the decision to use surveys as the main data collection technique.

The reasoning of Nardi (2006), as to gain a more reliable outcome by using the same standardised questions for all research participants, formed also the basis of the decision on using the same questionnaire for professionals and operatives. To equate two so different groups of construction workforce, regarding especially their educational and job background, was central in this study, in order to get comparable results and to not overcharge one group.

As the survey was a business survey and not a household one, different concerns regarding confidentiality and sensitivity of responses, i.e. employees' responses concerning their employers, had to be considered (Lynn, 2008). The type of data collected was highly sensitive, as it was asked for the respondents' full names in order to map the knowledge network correctly. Therefore it was stated on the participant information sheet (Appendix A) and the questionnaire (Appendix C) that the data will be treated in a strictly confidential manner and will not be revealed to employers at any time. This was additionally mentioned during questionnaire administration.

A lot of effort was put into the questionnaire design, as the main difficulty in multinational surveys lies in generating valid and reliable data for both national contexts, which is also comparable across their contexts (Harkness, 2008). An important decision to be made in the beginning was whether to ask the same questions to both populations, i.e. countries. It was decided to apply a *simultaneous ASQ (ask the same questions) approach*, since data collection was carried out concurrently (Harkness, 2008). Furthermore the survey was designed *multilingual*, in English and German. Both questionnaires were produced at the same time, which is also known as a *classic decentring procedure* (Harkness, 2008). However, it was vital during the design of the questionnaire to ensure that the questions did not contain culturally tailored language, as this can be regarded as culturally biased in a comparative research (Harkness, 2008). It was crucial that the two different questionnaires are consistent and no language or culture dominates the other (ibid). Moreover many construction workers in the UK and Germany are foreign immigrants, who might not be completely fluent in either language. Hence the questionnaire had to be designed in a rather simple language in order to make it more accessible and culturally neutral for all participants. Since the researcher is a German national living in the UK, there were no difficulties encountered with translation. The questionnaire can be found in Appendix C.

During data collection the self-administered questionnaires were mainly distributed to larger groups of people in port-a-cabins on the construction sites. The researcher was present and available for questions and assistance at all times. This way the number of respondents was relatively high. This approach was also chosen as it was considered to be helpful to illiterates and foreigners, who could neither speak nor read the questionnaires, and therefore needed assistance. This in fact did only occur twice during data collection. One respondent was illiterate. Furthermore the researcher had to assist another respondent with translating the questions into French. Moreover this kind of questionnaire distribution enabled a small scale participant observation, as the respondents started discussing questions of the questionnaire or general issues on sustainable construction. Through this an additional, though much smaller, set of data was collected, as described in section 5.5.2.3.

5.5.2.1. The Social Network Perspective

Through SNA it is possible to understand the network structure and roles with the use of simple patterns of relationships based on only one event of data collection with a minimum effort regarding time and money (Müller-Prothmann, 2007). Pryke (2008) argues that although SNA is a quantitative method, it is still able to explore the more interpretative contexts of construction industry. In fact most of the data collected for SNA is quantitative, though has a qualitative nature, as relations between entities, in this case individuals are investigated. Additionally SNA is a very effective method regarding comparative studies in an industry, which renders comparisons difficult by the unique nature of construction projects (Pryke, 2008). As Hanneman and Riddle (2005) argue that boundaries of social networks can easily be expanded by replication of the population. Thus a hypothesis can be tested by studying several networks, i.e. populations.

Boundary definition of the actor set under investigation is a vital aspect of SNA. Laumann, Marsden and Prensky (1989; in Wasserman, Faust, 2009) identify two different approaches on defining the population under examination. One is the *nominalist approach*, where the network boundary is defined by the researcher. This is similar to the so-called ‘positional approach’ (Scott, 2000). The second approach is called the *realist approach*, where the actors define the boundary of their network themselves (Laumann *et al.,* 1989; in Wasserman, Faust, 2009), which is similar to the so-called *reputational approach* (Scott, 2000). A combination of both, with an emphasis on the *nominalist approach*, was applied. The boundary of the networks examined was defined by the researcher as all participants working on one particular construction project. However, the design of the questionnaire allowed respondents to also name knowledge sources outside of this specific project. Nevertheless, Pryke (2008) declares that one possible outcome while applying the nominalist approach to construction research is a tendency towards higher levels of isolates. This issue will be further explored in the research findings in Chapters 6 and 7.

5.5.2.2. Questionnaire Design

There is a variety of ways to gather social network data. Techniques are e.g. questionnaires, interviews, observations or archival records, which are all common social and behavioural science procedures. Questionnaires are most commonly used and contain questions about the respondent’s ties to other actors (Wasserman and Faust, 2009).

The questionnaire is divided into three main sections.

The first section generated data regarding the ‘general actor attributes’, such as name (Q1), age (Q2), gender (Q3), nationality (Q4), company affiliation (Q5), job level in the hierarchy (Q6), length of time employed by the company/ in this position (Q7), and educational background (Q9). Since knowledge perception is another actor attribute and a vital KT influencing factor, the questionnaire contained several questions on the awareness regarding sustainability, special training and application of knowledge on how to build sustainable (Q10-16).

The second part (Q17 and Q20) of the questionnaire was designed in order to map the knowledge flow in the construction project, i.e. aimed at collecting social network data. Wasserman and Faust (2009) put forward that the relations that are being studied can only be the ones that the respondent can report on, e.g. who they like or go to for advice. There are three different forms of SN questions:

- Roster vs free recall
- Free vs fixed choice
- Ratings vs complete rankings

Roster means that the researcher presents a complete list of network actors to the questionnaire respondent. However, this can only be constructed if the researcher knows all members in the actor set prior to data collection. A *free recall* means that the respondents are asked to name those people with whom they have this link of 'whatever the tie is under examination' (Wasserman and Faust, 2009). This alternative approach is also called egocentric technique. Each individual responds to a series of questions that generate names (Fischer, 1982; Burt, 2002; in Reagans and McEvily, 2003).

In a *fixed choice* design each actor has a fixed maximum number of ties to other actors in the actor set. If there is no limitation on the number of people that an individual can choose the question is designed as a *free choice* (Wasserman and Faust, 2009).

In addition actors can be asked *to rate* or *rank order* the other actors in the set for each measured relation, which reflects the intensity, i.e. strength of ties. *Ratings* require each respondent to assign a value or rating to each tie, whereas *complete rankings* require each respondent to rank their ties to all other actors (Wasserman and Faust, 2009).

Who (first and last name)	Company they work for	How often?					Time in Min	Why do you go to this person?	Your relation to this person	Subject discussed: Sustainable Materials Technologies Techniques
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				

Figure 5.2: Example of a Social Network Question

Figure 5.2 depicts an example of a SN question in this research. These were designed in the format of a *free recall* with a *free choice*. Hence respondents were rather asked to name those people with whom they transferred knowledge on how to build sustainably, compared to offering them a fixed roster with names to tick. Furthermore the participants could name as many people as they like, thus having more freedom in their replies (Wasserman and Faust, 2009). Moreover the results are a multi-relational data set, as the relationship to the other actors was also investigated. In addition to this there was a frequency matrix to tick on how often they asked or advised that person in form of a Likert scale. Thus the answers revealed some tie characteristics as well. Additionally they were also asked which subject area they are most likely to discuss with this person, i.e. sustainable materials, technologies, techniques or any combination of these. Thus more details on the tie content were discovered. As a result the data collected was very rich in terms of revealing various social network and KT characteristics.

The first case study had additionally the possibility for *complete rankings*. However, this case study showed the same results for the frequency matrix as for the rank order, i.e. the respondents ranked those higher with whom they communicate more often. Therefore the rank order was replaced by an indication of the length of each communication in minutes, giving more detailed information on duration of each KT.

The responses of the questionnaires were validated with the cross-validation method used by Krackhardt (1990; in Hansen, 2002). Hence the respondents were also asked who comes to them for help/ advice regarding how to build sustainably (Q20). In addition question 8, i.e. to whom they report to and how often, was used for triangulation as well.

The third section of the questionnaire was designed in order to get more information on the preferred KT methods used by the actors. Therefore Questions 18, 19, 21 and 22 investigate which methods were first used in order to seek the knowledge, and secondly in order to receive this required knowledge. This duality was meant to reveal, if knowledge might be sought using one method, while given using a different one, thus allowed filtering the methods.

Questions 23 and 24 gave the research participants the possibility to make suggestions on how to improve the KT in this construction project.

The participant information sheet can be found in Appendix A, the consent form in Appendix B and the questionnaire in Appendix C.

5.5.2.3. Participant Observation during Questionnaire administration

Bryman and Bell (2007) argue that participant observation is the best-known data collection method in business and management research. The researcher locates him-/herself in the social setting under examination and observes it, whereas the amount of actual participation can vary a lot (ibid).

In this study the behaviour of research participants in a social situation in a particular location was observed (Spradley, 1980). It was found to be helpful on many terms to administer the questionnaires rather to groups of individuals at the same time and place, than handing them out one by one and leaving it to the respondents to fill them in their free time and return them later. Firstly, this way the response rate was relatively high. Secondly, the setting allowed the respondents to ask questions on the questionnaire or subject area. Thirdly, filling in the questionnaire while enjoying a coffee break and socialising with colleagues, seemed to have motivated the participants to engage in this research as well.

As questions were raised on sustainable construction, such as ‘how to define sustainability’ or ‘which materials are sustainable and why’, various discussions evolved. As a result a number of aspects of experiences and perceptions, which would have not been accessible without group interaction, were discovered. This is in line with Morgan (1997), who states that the chance to share and compare their ideas and experiences often let the interviewees make the most interesting points. As it was not the intention of this study to do participant observation, it was interesting to observe a discussion simply develop during data collection of the first case study. Nonetheless, this was unfortunately neither videotaped, nor voice recorded. Yet, the researcher took notes and tried to voice record out of memory shortly afterwards.

It is common in organisations that individuals in different positions have routine patterns of what they do and do not discuss with each other (Morgan, 1997). Additionally problems can arise through an opinion leader in the group, who tries to dominate the discussion (Bryman, 2008), risking polarization. As a result the dynamic of the group influences the data it produces. For instance some participants may withhold things, which they might have mentioned in an individual interview (Morgan, 1997). These aspects were considered during fieldwork. Nevertheless it was not possible to collect participant observation data for all case studies due to the differences in each data collection process. Please see section 9.4 – Limitations for more details on this issue.

5.5.3. Documentation Sources

In addition to the questionnaires, photos of the projects were taken. Moreover, when available, reports on the sustainability assessments of each project were gathered. Initially it was thought that a good quality sustainable built result can be defined as an achieved sustainability certificate, which could indicate a successful KT during the project. Nonetheless the continuous literature review showed that this is not always the case (Robinson, 2008; Bordass *et al.,* 2004). Hence these reports were used more in terms of providing additional information on the comparability of the projects regarding the levels of sustainability certificates.

Having outlined the data collection techniques chosen, the chapter will now move on to explain how the collected data was analysed.

5.6. Data Analyses

A large quantity of data was collected for five case studies, using the methods outlined above. Once this data was collected in the raw form it was first compiled into two databases using the Statistical Package for Social Sciences (SPSS) and Excel. Thereafter the data analyses were conducted in a number of stages using four different kinds of analysis, which are further explored in the following sections. The results are presented separately for each case study in Chapter 6 and 7.

5.6.1. Descriptive Statistics

Descriptive statistics were chosen over inferential statistics, as the focus of this work is to use SNA to analyse KT in each construction project, i.e. case study separately. As a result descriptive statistics were found to be sufficient in order to provide background information on the research settings and participants of the various case studies. Moreover simple univariate analysis in form of frequency tables became more important in the context of this study, as these represent the so-called 'general actor attributes', which might influence KT on how to build sustainably.

General KT enhancers and inhibitors were identified in section 3.4.2.5 and were divided into two main categories: actor attributes and knowledge transfer methods. As a result it was found to be important to conduct univariate analyses on the following variables:

Regarding the actor attributes:

- Age group
- Gender
- Nationality
- Job role
- Educational background
- Awareness towards sustainable construction
- Training received on sustainable construction
- Perceived training requirements on sustainable construction
- Perceived use of sustainable materials, techniques or technologies

Regarding the KT process:

- Which methods did the participants use in order seek knowledge?

- Which methods were used in order to give them the required knowledge?
- Was the required knowledge about sustainable materials, techniques or technologies?
- Frequency and duration of these KTs?

5.6.2. Cross Tabulation

Cross tabulation was an important part of the analyses, as it shows if and how variables relate to each other. Figure 5.3 provides an overview of the various relationships that were explored during the analysis stage.

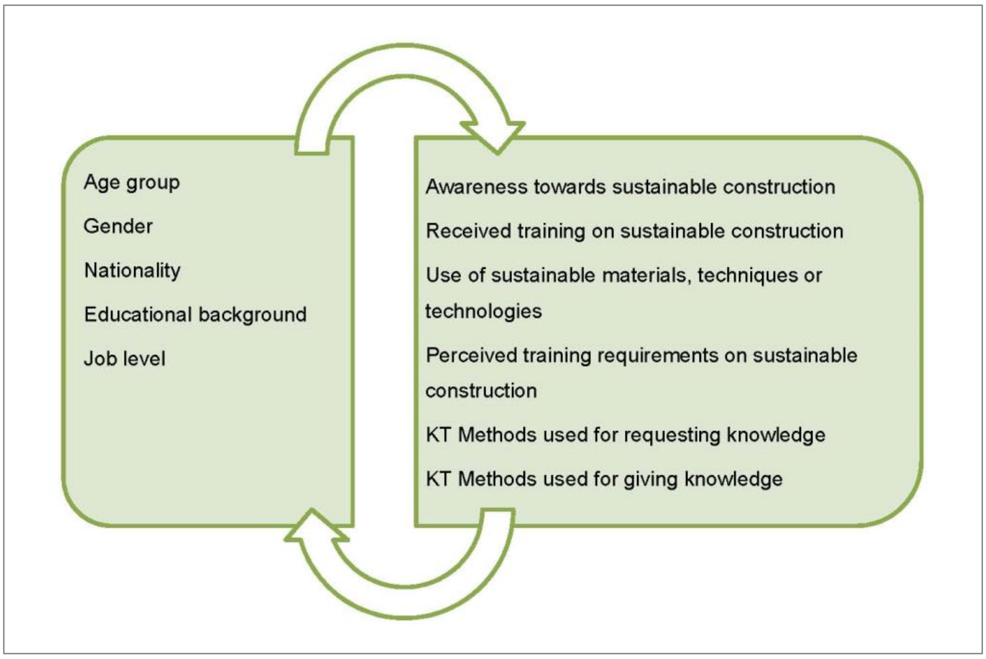


Figure 5.3: Cross Tabulations: Relationships under Investigation

Figure 5.3 shows that it was investigated to which extent the five actor attributes age group, gender, nationality, educational background and job level, influence the remaining four actor attributes that relate directly to sustainability, such as awareness towards sustainable construction, training received on sustainable construction and perceived training requirements, and perceived use of sustainable materials, techniques or technologies. Moreover the relationship of these attributes and the choice of KT methods was investigated, as these relate directly to the success of the KT.

5.6.3. Content Analysis

The small set of qualitative data was partly collected from open questionnaire questions and partly from participant observation data. This data was analysed using content analysis, including coding, counting phenomena, and comparing and contrasting relations between variables (Bryman, 2001). Bryman (2001) argues that content analysis is rooted in the quantitative research strategy, since it is a method of organising, retrieving and interpreting raw data through producing quantitative accounts of code categories.

The data collected from the questionnaires were any elaborations from respondents on the following aspects:

- a description of received training on sustainability, or reasons why they have or have not received such training (Q12)
- what kind of sustainable materials or technologies their companies or they use in their everyday work life, how they became aware of it, or why they do not use any sustainable materials or technologies (Q14)
- their opinion on why they feel the need or not for special training on sustainable construction, and what kind of training this would be (Q16)
- suggestions on what went well or wrong on this project regarding the transfer of knowledge on sustainable construction (Q23)
- any other comments (Q24)

In addition a small set of participant observation data was collected during questionnaire administration of some case studies, as described in section 5.5.2.3. As previously mentioned, the questionnaires were distributed to groups, which enabled discussions to evolve. Unfortunately it was impossible to cross-compare the participant observation data with the social network data, as it was not possible to allocate the short talks to specific participants.

5.6.4. Social Network Analysis

Chapter 4 elaborates on the possibility of using social networks in order to map the knowledge flow in project environments, i.e. producing so-called knowledge networks. It is against this background that the main aim of this research was to approach KT using a social network perspective. It was argued in section 4.4 that actor attributes are one major influencing factor of each network. These were investigated using descriptive statistics, as described in sections 5.6.1 and 5.6.2. Thereafter SNA was used to further explore the network characteristics which influence KT using the SNA software package UCINET (Borgatti *et al.,* 2002) and Net Draw for visualisation.

Social network data can be seen as simple descriptive data from an analytical point of view (Müller-Prothmann, 2007). However, the results can be analysed on three different levels: the whole network, clusters and individual actors. Müller-Prothmann (2007) states that SNA provides the means to measure, identify, visualize and analyse the social network of an entity and thus the KT within. Once the knowledge flow inside a social network is mapped, it is possible to suggest practical interventions, such as strengthening boundary-spanning KT or increase of inter-organisational relationships, to influence the network actors and thus enhance the KT between them.

It is vital to acknowledge that SNA should not be abused as an assessment tool for employers (Müller-Prothmann, 2007). Therefore, and out of general confidentiality reasons the very first step of SNA was to code the names of the participants. The analysis of social network data requires also coding for the tie content and the application of graph theory in order to visualise the structure of a network in a sociogram (Müller-Prothmann, 2007). The network information was displayed in an edge list format, where columns represent actors and the existing or non-existing ties between them. Table 5.4 presents an example.

Table 5.4: Example for network information matrix on frequency of knowledge transfers

CM1	CM5	3
CM1	CM6	1
CM1	CM7	1
CM1	Elec4	4
CM1	DL1	4
CM1	FO3	4
DL1	DL4	1
DL1	CM5	1
DL1	Log1	1
DL2	DL1	5
DL3	DL6	3

The first two columns of Table 5.4 represent the actors involved in a KT process. Here the left hand column is the knowledge receiver and the middle column is the knowledge source. Depending on the company they work for, the actors have the same code, e.g. CM1-9 are all working in various positions for the construction management company involved in this project. The right hand column in Table 5.4 shows the frequency of the KT. The ties can be presented dichotomous, i.e. 0 or 1, or valued (Hanneman, Riddle, 2005). In this study the ties are valued according to the frequency of KT, i.e. 1= less than once a week, 2= once a week, 3= more than once a week, 4= once a day, 5= more than once a day.

This matrix was produced in Excel and represents the data input for social network processing carried out with UCINET (Borgatti *et al.,* 2002). Scott (2000) argues that UCINET is one of four major programs available for personal computers. The other three are GRADAP, STRUCTURE and PAJEK. Key authors in SNA, such as Stephen Borgatti, Martin Everett and Linton Freeman contributed to the development of UCINET. Thus this program was used for the SNA. Moreover Scott (2000) put forward that UCINET has many powerful features, and is fast and efficient with a very wide range of available measures. For instance an additional tool is Net Draw for visualising the SN data in form of a sociogram. Net Draw possesses many features to depict the relational data, as shown in Figure 5.4.

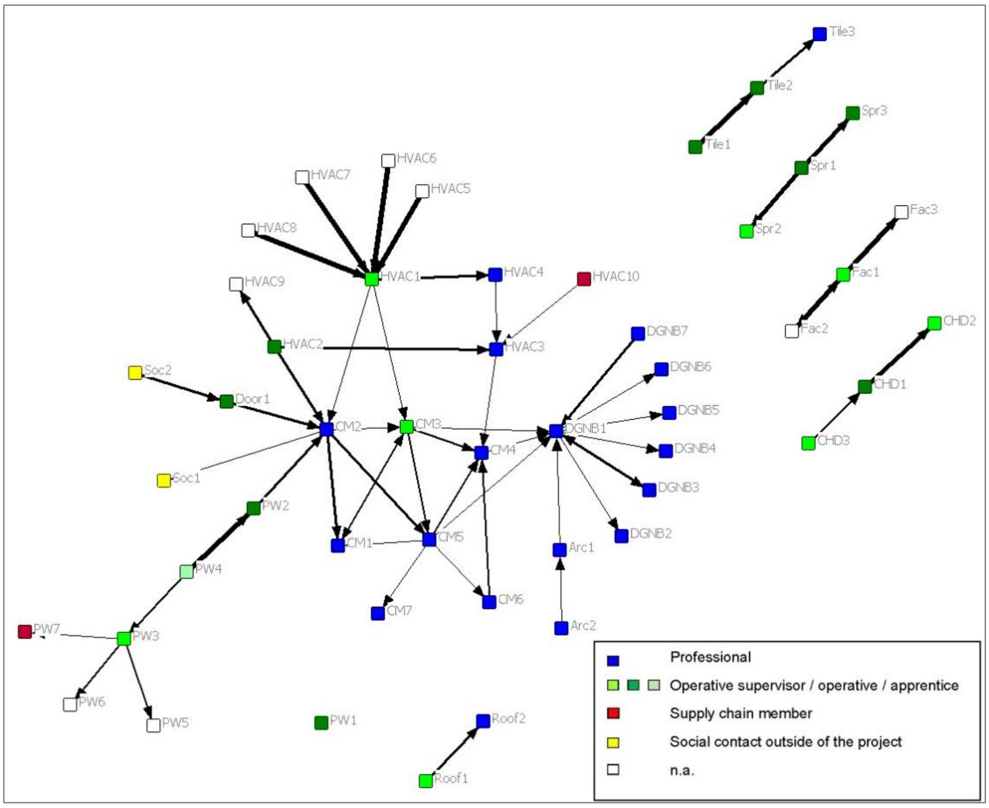


Figure 5.4: Example of a Sociogram in Colour

Figure 5.4 presents an example of a sociogram. It is the social network of case study Germany2, please see section 7.3 for more information on the codes. Each square symbolizes one actor, i.e. one construction project participant. The colours indicate the job level. This grouping was considered appropriate as KT in construction projects is widely assumed to be top-down according to hierarchy levels (Ugwu, 2005). In order to ease the further exploration and potential verification of this assumption, this colour grouping according to job levels was undertaken. Professionals are depicted in blue, construction workforce in green, supply chain in red and social contacts in yellow. The white squares represent actors with no data on their job level. The line weight of the links between the actors represents the frequency of the KT between two nodes, i.e. the more often they have exchanged knowledge on sustainable construction, the thicker the line, i.e. the stronger the tie (Hannemann, Riddle, 2005). Moreover, the links are directed in regards to the direction of who asked whom.

A sociogram of the knowledge network was produced for each case study to enable a discussion of how the network structure, i.e. network size, components, cut-points and actors, might have influenced KT, as described in section 4.4.1. In addition UCINET was used to calculate e.g. network density and actor centrality values. Here degree centrality was used to identify knowledge sources and consumers, whereas betweenness centrality identified gatekeepers who enhance KT (see section 4.4.3).

5.7. Conclusion

This chapter has presented the methodology and methods used in this research. Pragmatism was chosen as the methodological basis, as it seems to offer the most possible impact on the way construction industry conducts its business through the apply ability of the results to practice. This rationale was followed by introducing the conceptual framework, developed in due course of this study, in line with the third research objective.

The research was designed in order to best fulfil its main aim. A multiple case study approach was adopted as research strategy in order to explore the whole complexity of the KT. Subsequently the data collection tools were described, as mainly questionnaires with a combination of quantitative, qualitative and social network data. These were backed-up with literature and documentation sources plus a small set of participant observation data, if available. The constant exchange of ideas and discussions with practitioners from the field led to a continuous modification and improvement of the data collection tools throughout the whole process of data collection. The last section presented the data analyses as a combination of descriptive statistics, cross tabulations, content analysis and SNA.

Having justified the methodology and methods adopted in this study, the next chapter will present the findings of the two UK case studies.

CHAPTER 6

UK CASE STUDIES

6.1. Introduction

In order to fulfil the research fourth objective presented in Chapter 1, the conceptual framework was tested in practice through the analysis of case study data. The two UK case studies are presented in this chapter. Each of the two main sections begins with briefly outlining the research settings of each case study. Thereafter the findings of the descriptive statistics on the so-called actor attributes and their possible relationships are explored. This is followed by presenting the SNA. Here the results on network structure, density, tie contents, centrality and their relationships with each other, and with the actor attributes and chosen KT methods are examined, in order to determine to which extent they influenced KT on sustainable construction.

6.2. Case Study UK 1 - London

6.2.1. Research Setting

The construction project was a speculative development carried out by a main contractor and located in central London. It was a mixed use scheme of prime office, combined with a small residential and retail part with a total gross area of approximately 80,000 square meters. The project received with 73.2% an excellent BREEAM office 2006 certificate.

The project achieved the following scores in the eight main criteria groups of the BREEAM certificate, as discussed in section 2.4.2.

Table 6.1: Sustainable performance of project UK1

Criteria Groups	Credits	Weighted Section
Management	9	15%
Health	7	8.1%
Energy	13	9.8%
Transport	14	10.6%
Water	5	4.2%
Materials	3	2.5%
Land Use & Ecology	8	12.0%
Pollution	11	11%
Total	**70**	**73.2%**

The construction project was in its final stage at the time of data collection and due to be completed within the next three months. The data was mainly collected in an office on the construction site. Up to three groups of various involved trades filled in the questionnaire at the same time. However, most of the professionals preferred to fill in the questionnaire via email or in a personal meeting with the researcher. A total of 39 questionnaires and a small set of participant observation data were collected.

6.2.2. Actor Attributes

It has been established in section 3.4 that the personal attributes of actors do affect the KT they are involved in (e.g. Ruddy, 2000; Riege, 2005; Wilkesmann *et al.,* 2009). Hence, it was considered to be important to collect data on age, gender, nationality, educational background and the job level of the research participants in order to further explore of what scale this influence is, and if possible draw conclusions on how this team structure affects KT, hence team performance (Rosenthal, 1997). Additionally this could provide a better understanding of the industry's workforce's skills, training and awareness towards sustainable construction. First the univariate analyses of the actor attributes are presented, followed by their relationships, if any.

6.2.2.1. Age, Gender and Nationality

Figure 6.1 shows that the age range of the research participants in this case study was very diverse, with 15.4% between 16 and 24, 35.9% between 25 and 34, 20.5% between 35 and 44, 23.1% between 45 and 54 and only 5.1% between 55 and 64. As illustrated in Figure 6.2 most respondents were male (94.9%). In addition, practitioners from three different countries participated in this research, i.e. UK (92.3%), Rumania (5.1%) and Australia (2.6%) (see Figure 6.3). Since most participants were British and male no remarkable results were found in cross tabulations between these variables and others. Yet, as stated in section 3.4.1.1 this result might be rather limited, as the participants expressed their citizenship though not necessarily their cultural background. As a result 'age group' was singled out of these three variables for succeeding analyses.

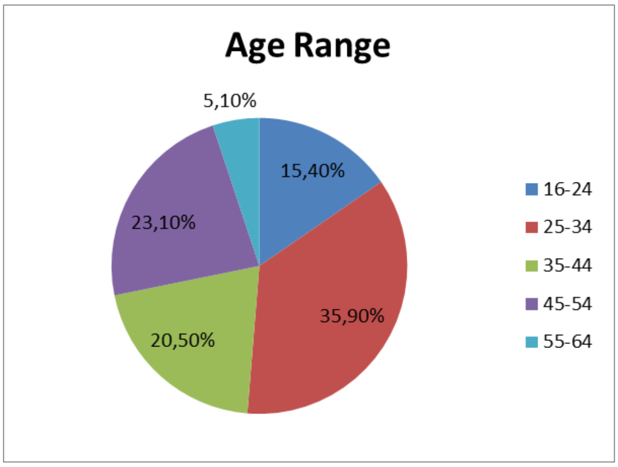


Figure 6.1: Age Range of Research Participants in Case Study UK1

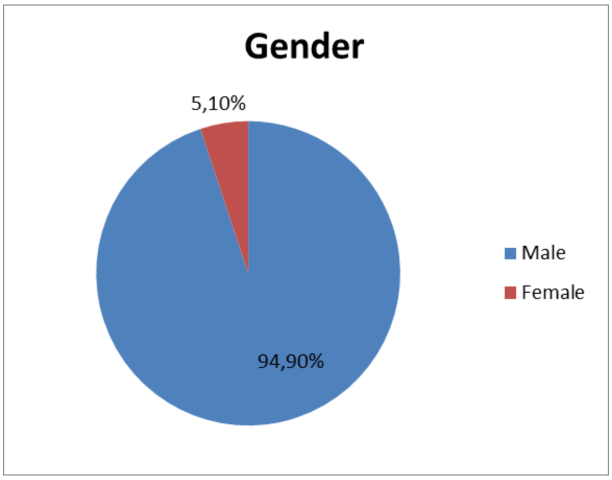


Figure 6.2: Gender of Research Participants in Case Study UK1

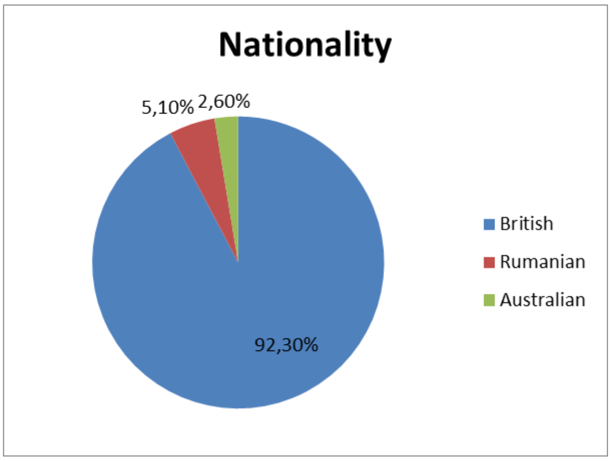


Figure 6.3: Nationality of Research Participants in Case Study UK1

6.2.2.2. Educational Background and Job levels

Literature (e.g. Egbu, 2004; Wilkesmann *et al.,* 2009) indicates that job level and educational background has an effect on knowledge perception and awareness. Since it was argued in section 3.4 that this again effects KT itself, it was considered vital to include research participants from all different job levels and with various educational backgrounds in order to get a wider perspective and examine this issue in more detail. Moreover as previously stated, it was considered vital to include the construction workforce, as they are crucial for the actual delivery of the building.

Figure 6.4 illustrates that the educational background of the research participants varied from 5.4% with no education or job training, 5.4% with a Bachelor's degree, 16.2% with a Master's degree and the majority with 73% had completed an apprenticeship. Figure 6.5 shows that this case study included participants from various job levels, i.e. interns (2.6%), apprentices (10.5%), operatives (44.7%), operatives' supervisors (28.9%) and professionals (13.2%).

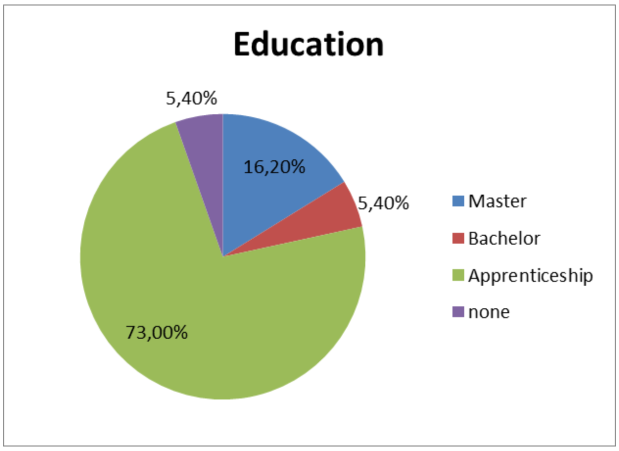


Figure 6.4: Educational Background of Research Participants in Case Study UK1

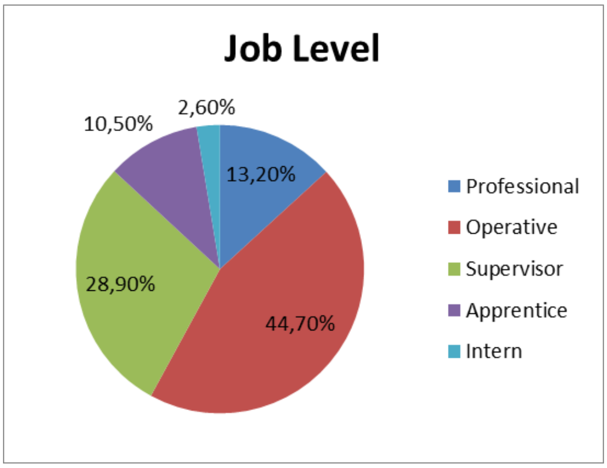


Figure 6.5: Job Levels of Research Participants in Case Study UK1

The cross tabulation presented in Table 6.2 confirms the strong relationship between 'educational background' and 'job level' as expected. As a result the succeeding analyses in this case study will equate 'educational background' with 'job level'. Hence any bivariate analysis conducted with job level, stands for both variables.

Table 6.2: Cross Tabulation between Educational Background and Job Level in Case Study UK1

	Job Level					Total
Educational Background	Professional	Supervisor	Operative	Apprentice	Intern	
None	0	0	1	1	0	2
Apprenticeship	0	10	14	3	0	27
Bachelor	0	1	0	0	1	2
Master	5	0	1	0	0	6
Total	5	11	15	4	1	37

6.2.2.3. Awareness of Sustainability

The existence, perception and awareness of knowledge on how to build sustainably, was tested by asking, if participants were aware that this was a sustainable construction project striving for a BREEAM certificate. They were also asked, if they were aware of their company's possible use of sustainable materials or technologies, and whether they could name and elaborate on those. This enabled a triangulation of their replies in regards to, whether these materials and technologies are actually sustainable or rather simply perceived as sustainable by research participants. This again links back to how knowledgeable the workforce actually is.

Figure 6.6 shows that only 51.3% of the respondents in this case study were aware that the construction project they were working on strived to achieve a BREEAM certificate. This result can be considered as rather low compared to the other case studies.

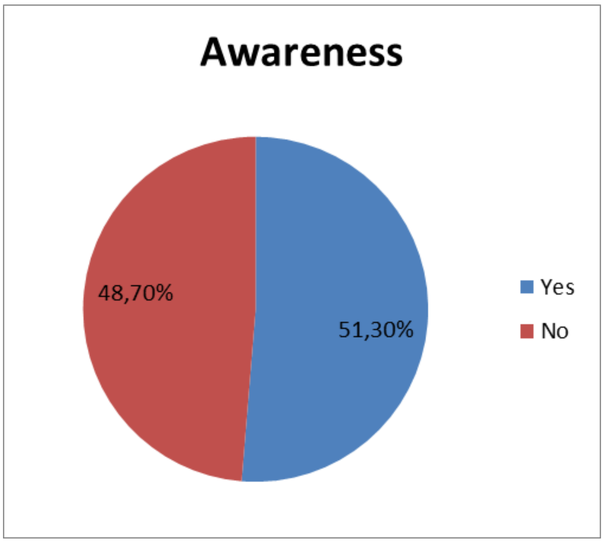


Figure 6.6: Awareness of Sustainability of Research Participants in Case Study UK1

When investigating this matter further it was found that levels of awareness of sustainability are spread throughout the various age groups (see Table 6.3). Hence it is clear that there is no link between these two variables.

Table 6.3: Cross Tabulation between Awareness and Age Group in Case Study UK1

	Awareness		Total
Age Group	**Yes**	**No**	
16-24	3	3	6
25-34	8	6	14
35-44	4	4	8
45-54	5	4	9
54-65	0	2	2
Total	20	19	39

Table 6.4 shows that the research participants, who were not aware of the sustainability target of this project, were only in the construction workforce, i.e. operatives, apprentices and their supervisors. Thus this finding indicates a link between awareness and job level.

Table 6.4: Cross Tabulation between Awareness and Job Level in Case Study UK1

	Awareness		Total
Job Level	Yes	No	
Professional	5	0	5
Operative	5	12	17
Supervisor	6	5	11
Apprentice	2	2	4
Intern	1	0	1
Total	19	19	38

Although awareness was widely spread between the different job levels, it is obvious that the unawareness was only within the construction workforce. This is supported by two operatives who declared: '*I didn't know there was a certificate called BREEAM'*. One participant stated that '*only supervisors and managers are made aware of the fact that this is a sustainable construction project'*. Thus the operatives again only become aware of it, if their supervisors decide to inform them. Hence the large unawareness of operatives in this project might be due to this chosen way to manage project knowledge.

When asked how they became aware of the sustainability goal of this project, replies again varied depending on the job level. Operatives rather stated e.g. '*from my supervisor'* or '*through using materials'*, while professionals stated '*through reminders, updates and meetings*' or '*through colleague knowledge, in-house seminars and wider reading'*. Nevertheless, these statements suggest that depending on the job level, project participants transfer knowledge using different methods. This issue is further explored through linking the actor attribute job level to the SNA results on KT methods in section 6.2.3.8.

6.2.2.4. Perceived Use of Sustainable Materials and Technologies

Figure 6.7 summarizes the responses to the question whether the research participants were aware, if their companies use some kind of sustainable material or technology. Here 56.4% of the answers were positive. It is interesting that 5.1% more were aware of them using some kind of sustainable material or technology within their own company, but did not necessarily connect this with an overall aim of the project to achieve a sustainability certificate (see Figure 6.6 in the previous section). As you can see, 33.3% claimed that their companies do not use any sustainable material or technology. However, it is not clear, if these companies really did so or, if it is simply perceived this way by the research participants.

Unfortunately it was not possible to further investigate this matter through e.g. interviews, as explained in section 9.4 - Limitations.

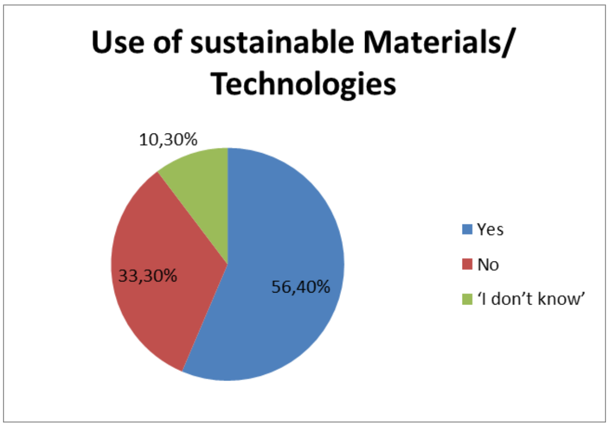


Figure 6.7: Perceived Use of green Materials or Technologies of Research Participants in Case Study UK1

The following cross tabulation confirms the relationship between the 'perceived use of sustainable materials' and 'job level', as most operatives and one apprentice were not aware of such use. This is also another confirmation of the results of the cross tabulation between 'awareness' and 'job level' depicted in Table 6.4 in the previous section.

Table 6.5: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Job Level in Case Study UK1

	Perceived use of sustainable materials and technologies			**Total**
Job Level	**Yes**	**No**	**I do not know**	
Professional	4	1	0	5
Operative	6	9	2	17
Supervisor	8	2	1	11
Apprentice	2	1	1	4
Intern	1	0	0	1
Total	21	13	4	38

The following cross tabulation shows that there is no link between the 'perceived use of sustainable materials/ technologies' and 'age groups' in this case study.

Table 6.6: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Age in Case Study UK1

	Perceived use of sustainable materials and technologies			Total
Age Groups	Yes	No	I do not know	
16-24	3	1	2	6
25-34	7	7	0	14
35-44	5	2	1	8
45-54	7	1	1	9
55-64	0	2	0	2
Total	22	13	4	39

The respondents elaborated further on their use of sustainable materials and technologies and this was analysed using content analysis, hence was coded and then the phenomena were counted, as described in section 5.6.3. The results are summarised in Table 6.7. This data derives only from the respondents, who elaborated further on this topic. Thus the percentage of 'no use of sustainable materials' (28.2%) does not match with the replies of question on 'companies' use of sustainable materials and technologies' (33.3%) shown in Figure 6.7.

Nevertheless, the materials and technologies named by research participants are for the most part in fact sustainable. Some unclarity exists only for metal and stone. This suggests that amongst those who elaborated on this matter, there is a very high level of understanding and awareness about sustainable materials and technologies.

Table 6.7: Perceived Use of sustainable Materials/ Technologies of Research Participants in Case Study UK1

Code	Count	Percentage
Do not use sustainable material	11	28.20%
Do not know	7	17.95%
No actual usage due to the nature of the job, i.e. professionals	5	12.82%
Timber / wood	4	10.25%
Recycled calcium sulphate boards	4	10.25%
Metal	3	7.69%
Solar panels / PV	3	7.69%
Plasterboard	2	5.13%
Insulation	2	5.13%
Rainwater harvest system	2	5.13%
Stone	2	5.13%
Low energy lighting	2	5.13%
Waste control	1	2.56%
Air/water diversity across systems	1	2.56%

Table 6.8 compares the awareness of the sustainability goal of the project with the perceived use of sustainable materials and technologies. The responses are spread out suggesting that there is no link between 'awareness' and 'perceived use of sustainable materials/ technologies'.

Table 6.8: Cross Tabulation between perceived use of sustainable Materials/ Technologies and Awareness in Case Study UK1

	Perceived use of sustainable materials and technologies			Total
Awareness	**Yes**	**No**	**I do not know**	
Yes	13	6	1	20
No	9	7	3	19
Total	22	13	4	39

6.2.2.5. Received and Required Training on Sustainable Construction

The training of each individual has an obvious effect on their knowledge and awareness towards sustainability issues and skills, as knowledge should increase through training (Ugwu, 2005). In order to examine this in more detail, questions on training were asked. Figure 6.8 shows the results for training received, while Figure 6.9 depicts the perceived requirement for specialised training on sustainable construction.

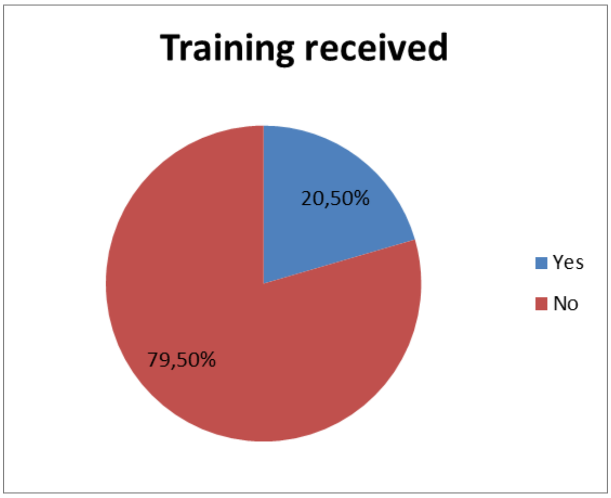


Figure 6.8: Received Training on sustainable Construction by Research Participants in Case Study UK1

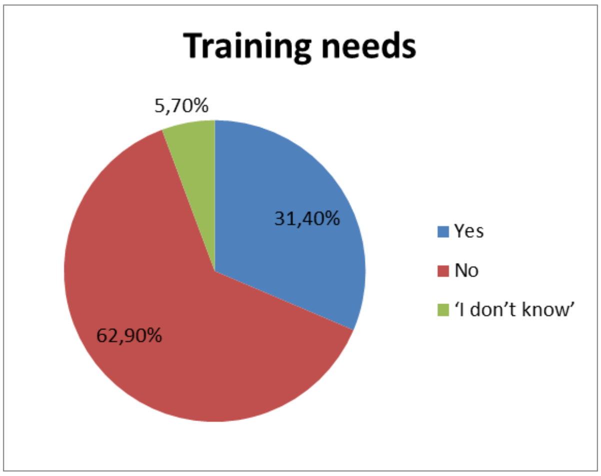


Figure 6.9: Perceived Requirement for Training on sustainable Construction by Research Participants in Case Study UK1

As indicated in Figure 6.8, out of all respondents only 20.5% stated that they have had a special training on sustainable construction, while 31.4% acknowledged the requirement of such specific skills. This means that more research participants of this case study feel they require training on sustainable construction than actually received it.

It was considered important to further examine whether there are any relationships between the actor attributes ‘training’ and ‘age group’, and ‘training’ and ‘job level’.

Table 6.9: Cross Tabulation between received Training and Age Group in Case Study UK1

	Received training		**Total**
Age Group	Yes	No	
16-24	1	5	6
25-34	2	12	14
35-44	3	5	8
45-54	2	7	9
54-65	0	2	2
Total	8	31	39

Table 6.10: Cross Tabulation between Training Needs and Age Group in Case Study UK1

	Perceived training needs			**Total**
Age Group	**Yes**	**No**	**‘I don’t know’**	
16-24	1	4	1	6
25-34	2	10	0	12
35-44	3	3	1	7
45-54	4	4	0	8
54-65	1	1	0	2
Total	11	22	2	35

Interesting points of the cross tabulations presented in the Tables 6.9 and 6.10 are that 12 out of 31 respondents, who have not received a special training on sustainable construction, are of the age group 25-34. Additionally 10 of these 12 stated that they do not feel they require such training in the first place. This is remarkable as this is the age group, which can be assumed to be still on training or finished not too long ago. As sustainability in the built environment is a well-discussed subject and emerged over the past two decades, these numbers might indicate that this has not yet been implemented enough in education and job training. This could rely back to the statement put forward by Steedman (2011) that vocational training varies widely between the UK and continental Europe in terms of duration and quality, as discussed in section 2.5.2. As a result Tables 6.11 and 6.12 explore whether the received training and perceived training needs depend on the job level. Results on this issue could provide further details on the implementation of sustainability in the vocational training of construction jobs.

Table 6.11: Cross Tabulation between Job Level and received Training in Case Study UK1

	Received training		Total
Job Level	**Yes**	**No**	
Professional	1	4	5
Operative	3	14	17
Supervisor	4	7	11
Apprentice	0	4	4
Intern	0	1	1
Total	8	30	38

Table 6.12: Cross Tabulation between Job Level and Training Needs in Case Study UK1

	Perceived training needs			Total
Job Level	Yes	No	'I don't know'	
Professional	1	4	0	5
Operative	5	7	1	13
Supervisor	4	6	1	11
Apprentice	1	3	0	4
Intern	0	1	0	1
Total	11	21	2	34

Out of the eight people, who actually received a specialised training, seven were part of the construction workforce, i.e. operatives, apprentices and their supervisors, as shown in Table 6.10. Interestingly only one professional received such training. One could have assumed that professionals might receive more training on sustainable construction than operatives due to their more managerial positions, which these cross tabulations disprove for this case study. However, since the professionals do have a different educational background, they might have received their knowledge on sustainable construction at university, depending on their age. Nevertheless this suggests, as previously stated, that sustainability has not yet been implemented enough into vocational training, but is rather taught through additional training. Table 6.13 summarizes the statements of the participants on the nature of these trainings.

Table 6.12 shows a wide spread of answers regarding the question whether such training is actually required, hence no prominent link with job levels was detected. Nevertheless this shows a general lack of agreement as to the necessity of special sustainability training.

In order to explore the issue of training and skills on sustainable construction, the research participants were asked to elaborate further on the question what kind of training they received. The purpose is to provide an overview of the current situation regarding what training is available and required. Moreover it might help to gain an understanding, if the workforce is actually knowledgeable on what sustainable construction training is, which in itself again relates back to their general awareness towards sustainability in the built environment. As argued in section 3.4 the perception and awareness of one's own knowledge affects KT positively (e.g. Egbu, 2004). The results are presented in Table 6.13.

Table 6.13: Perceptions of sustainable Construction Training in Case Study UK1

Code	Count	Percentage
I had no training	26	66.66%
On the job training	6	15.38%
The materials do not need any special skill, as they are very similar to any non-sustainable material	4	10.26%
1 day course in-house	3	7.69%
Apprenticeship	3	7.69%
BRE related	2	5.13%
Training by manufacturer	2	5.13%
Sustainable design is delivered with specialist consultants / sub-contractors	2	5.13%
University	1	2.56%
Only directions are offered	1	2.56%
Learnt by asking different people	1	2.56%
Learnt my skills on site and from other workers, and learnt a lot by watching others	1	2.56%
Toolbox talk	1	2.56%
Timber-course, land lease	1	2.56%
All operatives require L2 NVQ some L3 NVQ	1	2.56%
PASMA, IPAF, MVQ2 Dry lining, LIF	1	2.56%
CSCS level 2	1	2.56%
Harness, scissor lift and cherry picker, abrasive wheel, PULSA	1	2.56%
PV systems require training	1	2.56%
Sustainable design is an item integrated from beginning and therefore delivers with project	1	2.56%

Table 6.13 shows that some of the perceptions of training on sustainable construction are simply wrong, for instance courses on land lease. This might lead

to the conclusion that some research participants simply listed any training they have ever received, without differentiating whether it was on sustainability. Nevertheless, other statements such as training by the BRE, university or apprenticeship prove that institutions do provide training on sustainable construction. The 'training by a manufacturer' was a German company, which is an interesting coincidence in the context of this study regarding its comparative nature between the UK and Germany.

The comment of 'employing sustainable specialists' (Table 6.13) goes along with literature (Rohrbacher, 2001) that such a project requires more specialised companies, as argued in Chapter two. The last statement was made by an architect, who assumed that sustainable design is simply delivered without any difficulties. This suggests unawareness of the performance gap of sustainable buildings that forms the basis of this study.

The most interesting comments for this research project shown in Table 6.13 are the ones that do concern how participants did receive their knowledge on sustainable construction and are hence about KT methods.

- On the job training
- 1 day course in-house
- Training by manufacturer
- Only directions are offered
- Learnt by asking different people
- Learnt my skills on-site and from other workers, and learnt a lot by watching others

The six knowledge transfer methods above were also part of the KT process box of the conceptual framework presented in section 5.3.2. Hence in terms of testing the conceptual framework in practice, these statements were taken into account. It was investigated whether the results of the other case studies confirm this trend.

The next section examines the social network characteristics, their relationships and to what extent they influenced KT on sustainable construction.

6.2.3. Social Network Characteristics

Figure 6.10 illustrates the knowledge transfer network of this case study. The colour coding and line weights are displayed according to the description provided in section 5.6.4. Please also see the key at the end of each case study for clarification of figures as the chapter progresses.

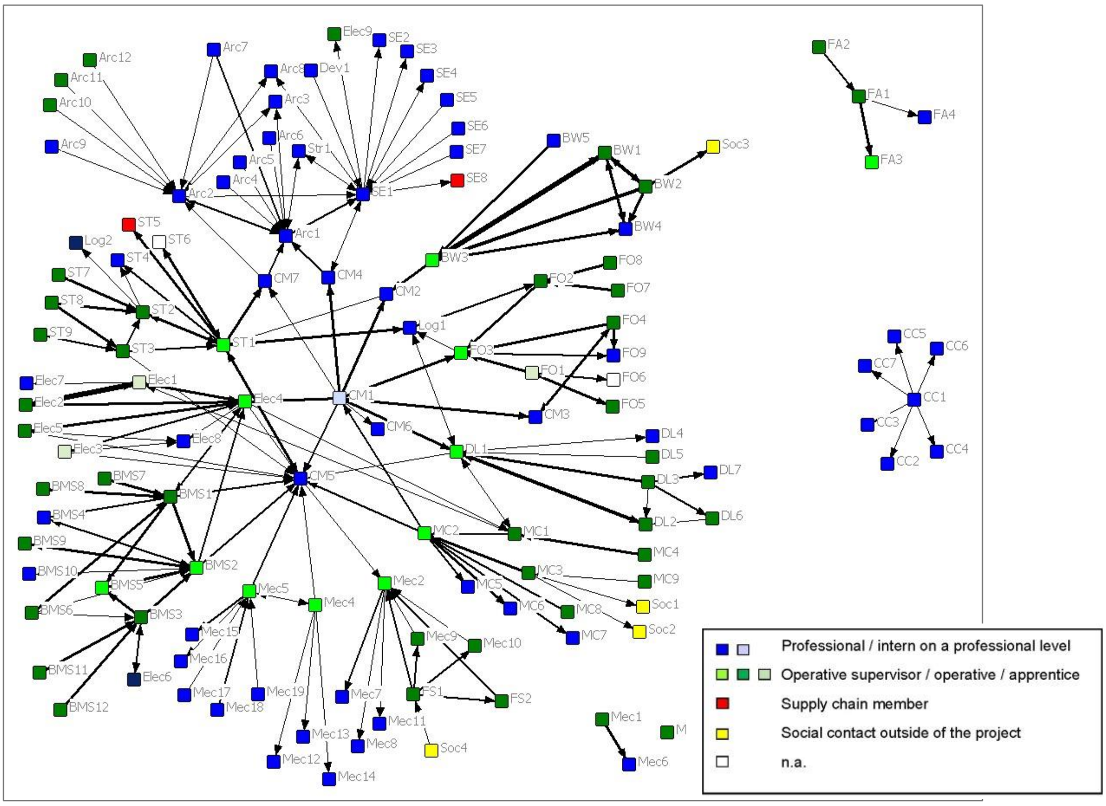


Figure 6.10: Knowledge Transfer Network of Case Study UK1

6.2.3.1. Size of the Network

This network comprises of 125 nodes and is rather large in comparison to the other case studies examined in this research project. As you can see in the fold-out key at the end of this case study, only 39 out of the 125 were research participants. The other 86 actors were named by them. Nevertheless, apart from the three social contacts, all other actors were involved in the same construction project. As stated in section 5.5.2.1 the network boundary was defined as all participants on one particular sustainable office construction project. The sampling, which led to these 39 research participants is presented in section 5.4.2.

6.2.3.2. Network Structure

The network structure consists of one main component on the left hand side, and only three smaller components and one isolate, i.e. Mec3, on the right hand side of Figure 6.1. The main components includes the following companies: construction management, dry lining, metal ceilings, building management systems, brickwork, mechanical contractors, electrical contractors, fire stopping contractors, stonework, commercial WC and joinery fit-out, architect, services engineer, structural engineer, logistics, developer and social contacts outside of the project. The employees of the construction company are, as expected, the most central ones and linking most of the other companies. The three small components are each one company, i.e. cost consultants, fire alarm sub-contractors, and part of the M&E contractors.

As for the cost consultants, one could argue that their involvement with the other trades might not be as vital for the built outcome as for other companies, i.e. they might not require knowledge on sustainable construction from other project participants in order to fulfil their job, compared to for example construction contractors. This could therefore be the reason why they are not connected to the main component. The same reasoning could apply to the fire alarm sub-contractors. Follow-up interviews could have provided a better explanation of this issue, but were unfortunately not possible, as described in section 9.4 - Limitations.

Three M&E contractors are left out of their team, which can be seen at the lower part of Figure 6.1. It is clear that the other mechanical contractors of the same team are well connected with each other, and with CM5, i.e. the project manager in charge, through the three supervisors, i.e. Mec2, Mec4 and Mec5. This main group of M&E contractors is, compared to other companies involved in this project well organised regarding their knowledge management. In this case the supervisors are the interface between the various team members and exchanging knowledge in both directions. Reasons for Mec1, Mec3, Mec6 not being involved with the others are most likely to be found in both, their behaviour as research respondents and their job description. Mec3 is an isolate, because he/she filled in the questionnaire, but left the SN questions blank. Additionally no one named him as a knowledge source on sustainable construction, probably because he/she is only responsible for the installation of boilers. Mec6 was not a research participant, but simply named by Mec1, who works as the commissioning engineer.

6.2.3.3. Cut-points and Hierarchy Models

As described in section 4.4 a cut-point is defined by e.g. Scott (2000) and Hanneman and Riddle (2005) as a node whose removal would divide one component into two or more. Thus it is important to identify the cut-points in this network. When discussing cut-points in this social network, the focus is on the main component of the network, since the three smaller components only possess one obvious cut-point in their centre. As you can see in Figure 6.11 the orange circle indicates cut-points in terms of linking the various participating companies with each other. Therefore, if these cut-points are removed, each company becomes a component without cooperating with other actors or companies any more.

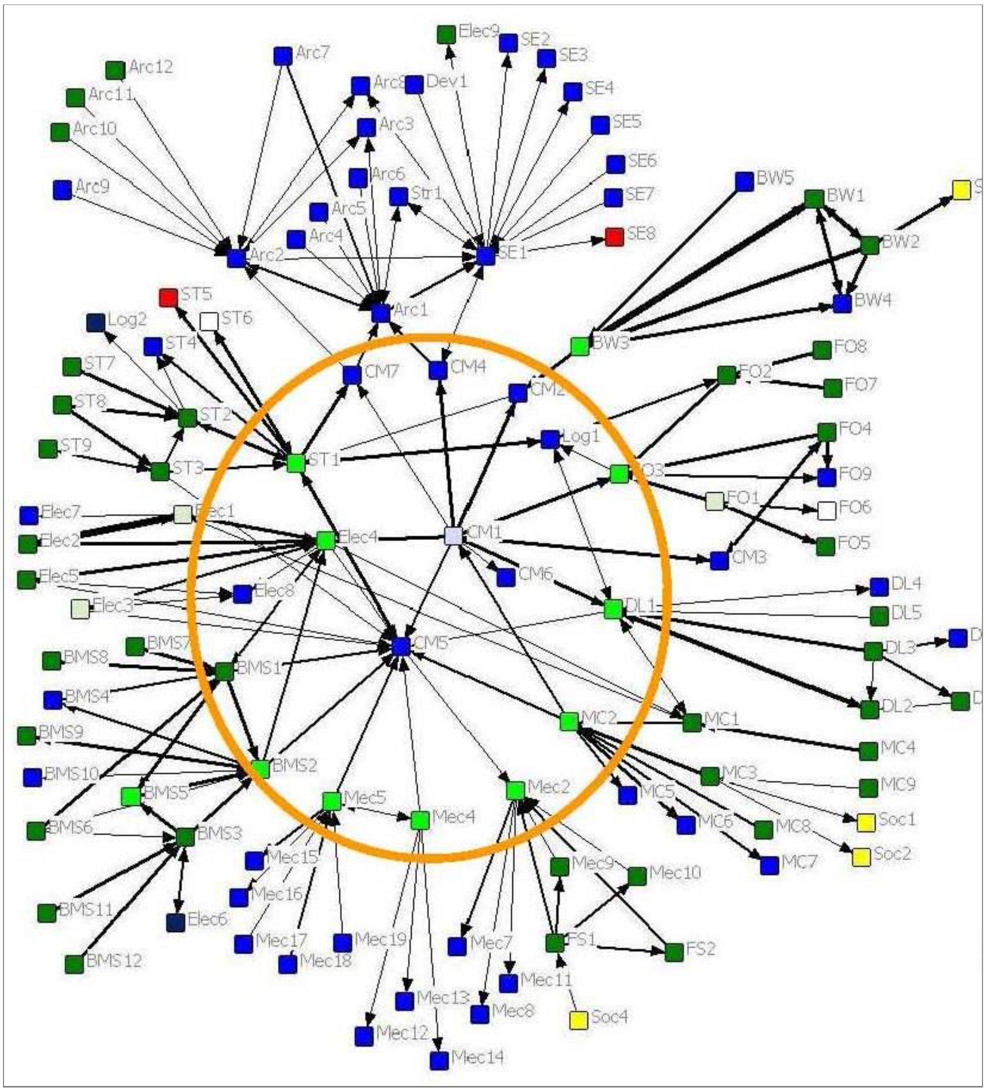


Figure 6.11: Knowledge Transfer Network of Case Study UK1 – Cut-points main Component

The supervisors of the operatives represent most cut-points, i.e. FO3, DL1, MC2, Mec2, Mec4, Mec5, BMS2, Elec4 and ST1. Each cut-point connects their immediate work team through the construction management company to the other teams. However, there is one exception in this network: BMS1. BMS1 is an operative in the building management systems company. Figure 6.11 shows that BMS1 acts as a cut-point for his team and is additionally well connected to other companies. It seems as, if regarding knowledge transfer, BMS1 is taking a supervisory position, while BMS5, who is a supervisor in this team is not acting as one. BMS5 is only connected to three other nodes and according to his/her network position cannot be considered as a cut-point. Nonetheless, this could be due to the fact, that BMS1 was a research participant, while BMS5 was just named by others. When further examining the knowledge that was transferred through these actors, it strikes that BMS1 seems to have specialist knowledge on materials and the techniques for their installation, as all KTs of BMS1 evolve around the combination of these two subject areas. BMS5 discusses combinations of all three subject areas, i.e. also technologies. The centrality measures in the following section will further explore the inter connectedness of BMS1 and BMS5.

CM4 and CM7 are important cut-points, or are sitting on structural holes, in this network as they represent the only connection from the central part of the main component, i.e. the actual construction workforce to the architects and structural engineers, i.e. the design team. Hence this finding could indicate that the design team and the construction team are to some extent separated in their knowledge flow, with CM7 and CM4 standing at the interface of the two project stages, which these two work groups resemble. This network structure shows a clear division of the project stages design and construction. Nonetheless it was argued in section 2.5.3 that sustainability issues are changing the way construction industry is conducting its practice (Häkkinen, Belloni, 2011). As a result a so-called integrative planning process which supports an early cooperation of all participating companies was suggested (Rohrbacher, 2001; Häkkinen, Belloni, 2011). Yet this case study seems to have not adopted any new approach in handling project knowledge, as it shows to some extent professional silos as argued by e.g. WBCSD (2008) that are only connected through the construction management company. The network position of CM4 and CM7 can be explained by their job roles as package managers for the construction management company.

It is vital to explore further what kind of knowledge was exchanged through these two actors, CM4 and CM7. Both actors do receive and pass on knowledge on all three subject areas of sustainable construction, i.e. materials, technologies and techniques as defined in section 5.3.1. As a result this does suggest that CM4 and CM7 act as gatekeepers between the design and construction stage. The betweenness centrality calculations in 6.2.3.6 will explore this issue further.

Another interesting aspect regarding hierarchy levels in this network are the professionals in general. Besides a large group of professionals in the upper part of the main component, i.e. architects and structural engineers, the rest are scattered all over the network. Literature (e.g. Ugwu, 2005) argues that KT in construction projects is rather top down, i.e. supervisors being the interface between the operatives and professionals of their company and other actors in the network. Although most supervisors do act as interface between professionals and operatives, some professionals do request knowledge on sustainable construction from supervisors and operatives and not the other way around.

However, regarding the operatives, their supervisors and apprentices some participant observation data was collected during questionnaire distribution, as described in section 5.5.2.3. In an on-site office, with up to three groups of various involved trades filling in the questionnaire at the same time, several discussions evolved through questions raised. It was observed that the team structure and social standing affected the way they discussed these issues arising from the questionnaire, as well as different job levels and affiliation to different companies. For instance, apprentices did not participate in the discussions, but rather listened or observed. Furthermore some supervisors encouraged a discussion or not. If two companies worked together, hence knew each other better, they discussed questions more openly, indicating a link of trust, see section 4.4.3. For instance one operative was wondering about how to define a sustainable material and asked an operative from a different company about their delivery that day, as '*it said sustainable on the boxes'*. These aspects took place according to Schwarz *et al.* (2008), as part of a variety of respondents' behaviour, see section 5.5.2.3.

6.2.3.4. Relationship between Network Density and Tie Characteristics and Tie Contents

The network density is 0.0320 with a standard deviation of 0.3480. This value indicates a mean strength of all possible ties of 0.03, i.e. 3% of all possible ties are present in this network (Hanneman and Riddle, 2005). As discussed in Chapter 4 the maximum value would be 1.0, i.e. 100% of all possible ties being present. 0.03 is a very low value, implying that this network is rather sparse than cohesive. The standard deviation is larger than the mean, which indicates a great variation in the strength of ties, i.e. frequency of knowledge transfer.

In order to determine, whether the level of cohesiveness differ across the network additional calculations have been conducted according to the actor attribute 'job level'. As previously stated 'job level' is linked to 'educational background' thus no investigations on this variable were undertaken. Where only operatives are knowledge sources, the density value is 0.0368 with a standard deviation of 0.2194. Where only professionals are knowledge sources, the density value is 0.0258 with a standard deviation of 0.2128. While the operative's network is 1% denser and closer to the overall density, both deviations are similar. As a result there is no remarkable difference in network density depending on job levels.

As argued in section 4.4.2 the strength of a tie defines the type of knowledge that is transferred through it. Fernie *et al.* (2003) support this view by stating that weak ties seem to limit the exchange of tacit knowledge. The content and type of knowledge on sustainable construction was defined as a combination of both tacit and explicit knowledge in section 3.2 and 5.3.1. As a result it is considered vital to further examine the content and type of transferred knowledge in order to investigate whether this statement is true regarding this case study.

In section 5.3.1 it was argued that in order to better examine the knowledge flow in construction project teams delivering sustainable buildings, it is important to subdivide the knowledge into different categories according to their nature, i.e. content and type. Three different categories of knowledge content were determined as follows: new sustainable materials, new technologies and new building techniques. This division can help to better understand the link between network density and content and type of transferred knowledge. Moreover results could indicate what kind of knowledge is required more and by which workforce group. Table 6.14 gives an overview of the frequencies of the various tie contents of the 208 knowledge transfers on which respondents provided data.

Table 6.14: Tie Contents of Knowledge Transfers in Case Study UK1

Tie Content	Knowledge Type	Frequency Count	Valid Percentage
Materials	Explicit	45	21.6%
All: Materials, Technologies and Techniques	Explicit and tacit	45	21.6%
Materials and Techniques	Explicit and tacit	34	16.3%
Techniques	Tacit	20	9.6%
Materials and Technologies	Explicit and tacit	19	9.1%
Techniques and Technologies	Explicit and tacit	16	7.7%
Technologies	Explicit and tacit	10	4.8%
No data on tie content	-	19	9.1%

As shown in Table 6.14, the subjects discussed in this case study were generally very varied. The two most mentioned subjects are materials (21.6%), and all three subjects combined (materials, technologies and techniques) (21.6%). These are followed by materials and techniques (16.3%). These results were partially expected as it was argued in section 5.3.1 that new sustainable materials and technologies require adjusted or new techniques for their installation. As a result many questions might evolve around new materials/ technologies and techniques on how to build them in. Hence this finding supports this argument.

The discussed subject areas give further indications on the knowledge type transferred and thus can be linked back to the tie characteristics and the network structure. As argued in section 5.3.1 the new knowledge on sustainable materials only is considered to be explicit. Hence it can be better transferred through a sparse network with weak ties (Fernie *et al.,* 2003). This is in accordance to the finding above, i.e. materials being one of the two most discussed subject areas.

However, the new knowledge on techniques was previously defined as purely tacit in section 5.3.1 and was part of in total 55.2% of all knowledge transfers. Therefore the rather large amount of transferred tacit knowledge through this sparse network is an interesting finding and could indicate strong ties in this rather sparse network. As Augier and Vendelø (1999) put forward that tacit knowledge is best transferred through strong ties. This is also supported by Granovetter (1973) and Fernie et al. (2003), as discussed in section 4.4.2. Strong ties can be defined by long, close relationships with high trust (Granovetter, 1973). Therefore the results on the knowledge sources in section 6.2.3.7 provide further insights into this matter.

6.2.3.5. Relationships between Tie Contents and the Actor Attribute Job Level

In order to determine whether knowledge on certain subject areas is more in demand by a particular workforce group, cross-tabulation was carried out between tie contents and job level. The results are depicted in Table 6.15 and show the job level of the person, who asked for advice on sustainable construction.

Table 6.15: Tie Contents of Knowledge Transfers linked with Actor Attribute Job Level in Case Study UK1

	No data on tie content	**Materials**	**Technologies**	**Techniques**	**Materials and Technologies**	**Materials and Techniques**	**Techniques and Technologies**	**All three subject areas**	**Total**
Apprentice	16.66%	66.66%	0%	16.66%	16.66%	16.66%	16.66%	0%	100%
Operative	16.66%	11.90%	22.61%	5.95%	10.71%	3.57%	21.42%	7.14%	100%
Supervisor	36.95%	8.69%	13.04%	6.52%	2.17%	2.17%	19.56%	10.86%	100%
Intern	0%	0%	22.22%	0%	66.66%	11.11%	0%	0%	100%
Professional	21.66%	16.66%	30%	5%	5%	20%	6.66%	10%	100%

As indicated in Table 6.15 the most discussed subjects for each job level were:

- Apprentices → Materials
- Operatives → Technologies; techniques and technologies
- Operatives' Supervisors → Techniques and technologies
- Interns → Materials and technologies
- Professionals → Technologies; materials and techniques

These findings show, as expected, that all three main job levels (operatives, their supervisors and professionals) are concerned not only about the ‘what’ in terms of new sustainable building materials or technologies, but also about the ‘know-how’, i.e. techniques on how to build them in properly to achieve a good quality sustainable built result.

Nevertheless Table 6.15 also shows a slight difference depending on the job level. Apprentices were mostly concerned about materials. Operatives and professionals were also asking advice about technologies. As previously argued in section 6.2.2.3 ‘job level’ already had a strong influence on the awareness of sustainability. Therefore this finding indicates that the ‘job level’ of an actor also influences the tie contents, i.e. the subject areas discussed.

6.2.3.6. Relationships between Centrality Measures and the Actor Attributes Job Level and Age

As argued in Chapter 4, centrality measures are important in order to investigate which actor is more central, i.e. cross-linked than others (Wasserman and Faust, 2009) in regards to KT on sustainable construction. Actors with more ties, thus a higher degree centrality have various ways to access resources of the network and are hence less dependent on others (Hanneman and Riddle, 2005). Figure 6.12 shows the same network map as before, but with different node sizes. The node sizes are according to the average degree centrality of the actors, i.e. the larger the node the more central they are regarding KT on sustainable construction.

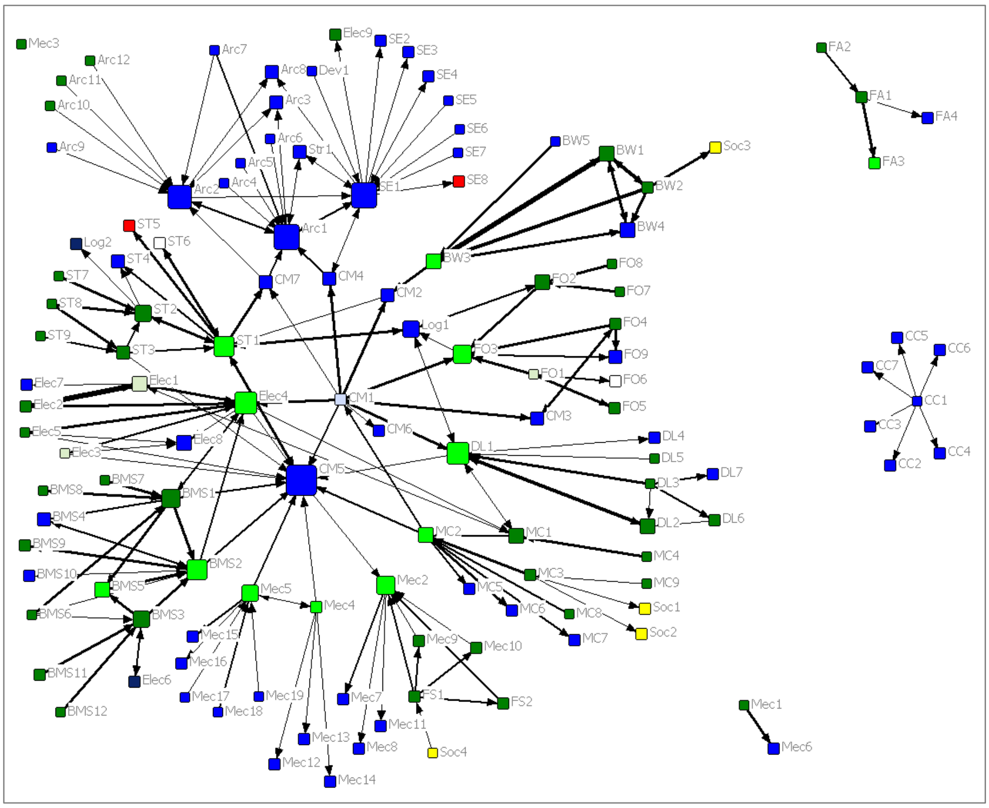


Figure 6.12: Knowledge Transfer Network of Case Study UK1 – Degree Centrality

In order to support Figure 6.12, Table 6.16 presents the five most central actors for in-degree and out-degree centrality and their respective other value. Yet, the degree centrality measures, shown in Table 6.16, are divided into in-degree and out-degree, while Figure 6.12 illustrates the average degree centrality, i.e. in- and out-degree combined.

As presented in section 4.4, another way to calculate the centrality of actors is closeness centrality and Eigenvector centrality. Closeness centrality describes integration or isolation of actors, i.e. the higher the value the more isolated the actor. In contrast to degree centrality, closeness centrality takes not only an actor's immediate links into account, but also the distance from each actor to all others of the network (Hanneman and Riddle, 2005). However, Hanneman and Riddle (2005) put forward that the closeness centrality measure might be misleading in larger networks. For this case the Eigenvector approach offers a way to triangulate the results and identify the most central actors in terms of the overall structure of the network (ibid). For the reason of completeness of analyses and to triangulate the degree centrality values, both calculations were conducted for this rather large case study only. The results proved a majoritarian accordance of all three different centrality calculations and can be found in Appendix D.

As argued in Chapter 4, the in-degree of an actor is the total number of other nodes which have ties towards it, while the out-degree is the total number of other nodes to which it directs ties (Scott, 2000). In this study the in-degree represents the number of people who ask an actor for advice. Hence the out-degree value represents, how many other actors someone asks questions on sustainable construction.

Additionally Müller-Prothmann (2007) divides actors into experts and knowledge consumers, as stated in section 4.4.4. The in-degree value identifies experts, i.e. knowledgeable people in the area of sustainable construction in this case study. Therefore knowledge consumers do not possess any in-degree centrality, but a high out-degree value. This indicates that they only ask others for advice but are rarely asked themselves. Meaning they ‘consume’ the knowledge without transferring it onwards, but also that they are perceived by the other network actors to not possess any expert knowledge on the subject and are hence never asked. Nevertheless, the combination of a high in- and out-degree value implies that the actor is either a knowledge broker, i.e. receives knowledge and forwards it, or an expert in one area and a consumer in another.

Table 6.16: Centrality Measures in Case Study UK1

Actor	In Degree	Actor	Out Degree
Elec4	26	ST1	30
BMS2	24	CM1	29
CM5	24	BW1	20
BW3	22	BW2	20
BMS1	21	BMS1	18
ST1	15	BW3	15
BW1	9	BMS2	15
BW2	6	Elec4	11
CM1	3	CM5	5

It is important to further investigate whether the in- and out-degree values are linked with the actor attributes job level and age groups, as shown below.

Perceived experts:

- Elec4, supervisor of the electrical contractors, age group: 45-54
- BMS2, supervisor of the building management systems company, age group: 35-44
- CM5, construction project manager in charge, no data on age
- BW3, supervisor of the brickwork company, age group: 25-34

- BMS1, operative of the building management systems company, age group: 25-34

Knowledge consumers or brokers:

- ST1, operatives' supervisor of the stonework company, age group: 45-54
- CM1, intern/ Professional of the construction management company, age group: 16-24
- BW1, operative of the brickwork company, age group: 35-44
- BW2, operative of the brickwork company, age group: 35-44
- BMS1, operative of the building management systems company, age group: 25-34

First of all there is no clear link between age and centrality of the actors in this case study.

It could have been assumed that the project manager CM5 is regarded as an expert not only on sustainable construction, but an over-all person to contact with any queries. Thus this outcome is as expected. However, the two supervisors Elec4 and BMS2 have slightly higher in-degree centralities than CM5. This outcome could indicate that specialists on building management and electrical systems are important experts in the area of sustainable construction. Hence their expert knowledge is required in a project aiming to achieve a sustainability certificate. Nonetheless, when examining this further, it is noteworthy that Elec4 and BMS2 both stated that they are not aware of the sustainability goal of the project and did not have any specialist training on sustainable construction. Moreover, BW3 and BMS1 are indeed aware of the goal, but did not undergo any sustainability training. Regarding the perceived need for such training, Elec4 elaborated '*we do not require such training, as specialist sub-contractors are hired'*. BW3 stated that training *'is not needed, as the materials we use are built in the same way as conventional ones.'* BMS1 and BMS2 are not sure whether they feel they require special training. As a result it can be assumed that they must have gained their expertise through experience. Nonetheless, it is remarkable that they do not seem to be aware of their knowledge.

The knowledge consumers are only operatives and one intern. This SNA finding supports the previous finding of the cross tabulation between the actor attributes on 'awareness' and 'job level', with only operatives being unaware of the sustainability goal of this project (section 6.2.2.3). Nonetheless this shows that the operatives might be unaware but do request knowledge on sustainable construction. Hence this might suggest better communication on sustainability down to operative levels.

As indicated in Table 6.16, BMS1 is in both in- and out-degree centrality as the fifth most central actor. This could indicate that BMS1 is a gatekeeper or knowledge broker as previously described, or he/she could simply be an expert in one area and a consumer in another. The following betweenness centrality calculations explore this issue further. Since betweenness centrality identifies gatekeepers as stated in section 4.4.3 (Scott, 2000), these calculations help to determine, which of the most central actors are also functioning as gatekeepers. These are important in this study as they pass on the knowledge on sustainable construction.

Table 6.17: Betweenness Measures in Case Study UK1

Actor	Betweenness
CM5	2952.347
CM1	2669.559
ST1	1072.805
CM4	1029.405
SE1	1026.952

Table 6.17 shows that the main gatekeepers in this network are:

- CM5, construction project manager in charge
- CM1, intern in the construction management company, i.e. bachelor student on placement
- ST1, supervisor of the stonework company
- CM4, professional for the construction management company
- SE1, professional service engineer

Three out of these five actors also had high centrality values. Thus this suggests that CM5, CM1 and ST1 are not only experts or knowledge consumers, but also act as gatekeepers. Moreover CM5 and CM1 have a betweenness value which is more than double than compared to the other actors. For CM5 this can be explained with the job role as project manager in charge. A remarkable finding is the role of CM1, the intern of the construction management company. As argued in section 3.4.1.3 it is easier to acknowledge a lack of knowledge to someone, who is lower in hierarchy. The intern had access to most knowledge from the construction management company, but is very low in the hierarchy, hence very approachable for other project participants. As a result it seems as if he/she actually improved the KT on sustainable construction in this project by being a knowledge source for the metal ceilings workforce. Their supervisor MC2 asked CM1 for advice on a combination of all three subject areas, i.e. materials, technologies and techniques, in the same frequency as the project manager (CM5). CM1 rather enquired information on materials combined with the techniques used to build them in. Hence this shows that CM1 does not seem to be a specialist in one area and a consumer in another, but a knowledge broker, who receives and transfers knowledge on a combination of subject areas.

CM4 was previously discussed in section 6.2.3.3 due to his/her network position as a cut-point, linking the construction workforce with the design team. Hence the high betweenness value confirms the importance of this actor in terms of acting as a gatekeeper between the two project stages design and construction. Interestingly, CM7 who was assumed to hold a similar network position was not identified as a gatekeeper.

As previously argued in section 6.2.3.3 the betweenness value of BMS1 should be explored further due to his/her network position, i.e. BMS1 is an operative at the building management systems company and acts as a supervisor. BMS1 has a betweenness value of 372.333 and is the 18th out of all 125 nodes in this network. In addition to this, as previously discussed he/she possesses expert knowledge on sustainable materials and the techniques required for their installation. As a result he/she can be regarded as a gatekeeper in receiving and providing knowledge on sustainable construction. Hence the betweenness calculations confirm the network position of BMS1 acting as a supervisor.

6.2.3.7. Knowledge Sources

This section explores the knowledge sources further, i.e. their role and what kind of relationship exists between the knowledge source and receiver, and why this person was chosen to ask for advice on sustainable construction. Please see sections 3.4.1 and 5.3.1 for the discussion on knowledge repositories and sources. The results were analysed with content analysis and are presented in Table 6.18. The research participants provided this information for 212 knowledge transfers, thus the number in the right hand column is the count.

Table 6.18: Knowledge Sources in Case Study UK1

Coding	**Total**
Colleague(on this project)	72
Manager (e.g. Labour, QHSE)	39
Colleague (from another company)	31
Supervisor	30
Friend	16
Client	12
Colleague (on another sustainable project)	6
Other: Nemesis, Improver, Mentor	3
Supply chain member	2
Relative	1
BRE contact	-
Total	**212**

In Section 3.4, it was argued that knowledge can be stored in many different repositories depending on its type (Argote, Ingram, 2000). During the development of the conceptual framework the various repositories were assigned to the three different categories: inside and outside the work team, and outside of the construction project. Please see section 5.3.1 for more details.

As shown in Table 6.18 the most common knowledge source with 72 counts was a colleagueon this project. A colleague is a lot more frequently consulted over a manager (39) or a supervisor (30). Indicating the choice of the knowledge source could to a certain extent be linked to trust, as by asking for advice the actor admits being less knowledgeable in the subject area. Trust does affect KT as argued in section 3.4.1.3 (Borgatti, Cross, 2003). Hence it might not be a surprise that colleagues are chosen over managers and supervisors, as there might be more trust based relations amongst them, than with someone from a superior job level. Moreover colleagues working on the same project together might have developed a so-called ‘transactive memory’ (Wegner et al., 1991), i.e. they know ‘who knows what’ (Berends, 2005). Please see section 3.4.1.2 for more details on this subject. In addition the results on the choice of the knowledge source confirm the assertion from section 6.2.3.4 that the majority of the ties are relatively strong and thus facilitate the transfer of the large amount of tacit knowledge. This is in line with literature (Augier, Vendelø, 1999; Granovetter, 1973), i.e. tacit knowledge is best transferred through strong ties. However, the results also show that these strong ties exist in a sparse network, which is a remarkable finding, as it shows that tacit knowledge can be transferred through a sparse network, if it consists of strong ties.

Therefore this questions existing literature and shows a need for more research on the matter of network density, tie strength and tacit KT.

Equally relevant seemed colleagues from other companies involved in the same project (31). This result is rather surprising, as it was assumed that due to the silo-based structure of the industry argued by e.g. WBCSD, 2008 or Kurul *et al.,* 2011, there would be no remarkable link found between various participating companies. This finding proves the contrary for this case study, at least regarding KT on sustainability during construction phase. When considering the network structure presented in Figure 6.11 one could already see that there is a rather good cooperation between the involved trades. Moreover the small set of participant observation data, discussed in section 6.2.3.3 supported this finding.

The research participants elaborated further on their choice for 85 knowledge transfers. 45 chose their knowledge source, because they were in charge. This confirms the choice of managers and supervisor displayed in Table 6.18. It can be assumed that practitioners in the field first ask the person in charge. The other reasons for choosing this knowledge source are divided into information (21), help (7), knowledge (5), trust and time (4) and experience (3).

In addition it was further examined, whether the previously identified perceived experts and knowledge consumers differ in their knowledge source choice. The following list shows who they prefer to ask:

Perceived experts:

- Elec4 manager
- BMS2 friend, supervisor, colleague, manager
- CM5 n.a.
- BW3 manager
- BMS1 supervisor, main contractor

Knowledge consumers or brokers:

- ST1 logistics, manager, package manager
- CM1 who I work closely with, manager
- BW1 manager, mate
- BW2 manager, father, colleague
- BMS1 supervisor, main contractor

The findings do not fully concord with the main outcome. The previously identified perceived experts and consumers seem to preferably ask managers and supervisors for advice on sustainable construction. According to Table 6.18 this is overall only the second, respective the fourth most named knowledge source. Only one perceived expert names a colleague as a knowledge source.

6.2.3.8. Relationships between Knowledge Transfer Methods and the Actor Attributes Age, Job Level and Actor Centrality

As argued in section 3.4.2, the KT process itself and thus the methods used, is an important factor of a successful KT. Therefore the various methods that were used in practice out of a variety of possible methods were inquired. Thus it was investigated, which methods were first used in order to seek the knowledge, and secondly in order to receive this required knowledge. This duality was meant to reveal, if knowledge might be sought using one method, while given using a different one, thus allowed filtering the methods.

The respondents filled in the methods used for each KT and were also given the opportunity to add methods, if they used others. However, no research participant has added any method, while all offered methods have been used. This might suggest that all important methods were covered in the data collection tools. Figure 6.13 presents the findings on this issue.

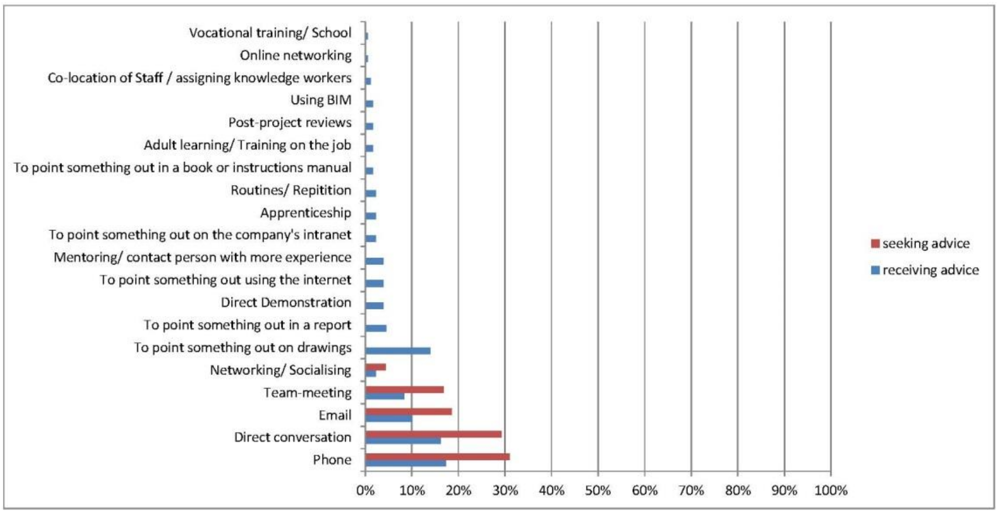


Figure 6.13: Knowledge Transfer Methods when seeking and receiving Knowledge in Case Study UK1

Figure 6.13 shows that the participants sought knowledge on sustainable construction by using phone and direct conversation nearly at the same level. This is followed by e-mails and team meetings. Only a small amount of questions were asked during socialising.

Most of the knowledge given was transferred using the same two methods, i.e. phone and direct conversation. As it could have been assumed for construction industry, this is followed by pointing something out on drawings, email and team meetings, which was confirmed through data analyses.

Therefore the nine most used methods to receive knowledge on sustainable construction in this case study were:

- Phone
- Direct conversation
- Email
- Team meeting
- Direct demonstration
- To point something out on a drawing
- To point something out in the internet
- To point something out in a report
- Mentoring

Most of these methods are according to literature (e.g. Haldin-Herrgard, 2000; Egbu, 2004) used to transfer rather tacit knowledge. As a result the choice of these KT methods gives further indications of the tie contents. As discussed in section 6.3.3.4, tacit knowledge was part of 55.2% of all the knowledge transfers that occurred. Thus this selection of KT methods provides further evidence of the transfer of tacit knowledge through this sparse network.

All methods were used to receive knowledge on sustainable construction. Nevertheless the two less used ones are vocational training and online networking. The fact that vocational training was used least, when receiving advice on sustainable construction might prove a deficiency in education indicated by e.g. Dixon, Colantonio and Shiers (2008), and Steedman (2011), previously discussed in sections 6.2.2.3 and 2.5.2.

It is vital to investigate the relationships, if any, between the various chosen KT methods and actor attributes, such as ‘age group’, ‘job level’ or ‘centrality’. Thus the following figures present the cross tabulation of these. As nine of the KT methods were previously identified as the most used ones, the focus is only on these.

Figure 6.14 illustrates the cross tabulation between ‘age group’ and chosen methods to transfer knowledge.

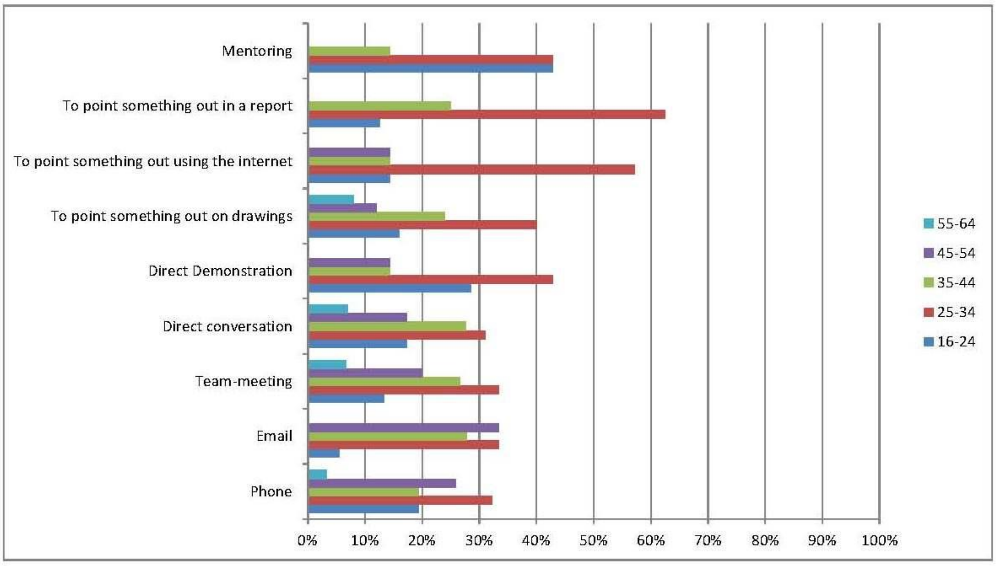


Figure 6.14: Knowledge Transfer Methods Cross Tabulation with Age Groups in Case Study UK1

As depicted in Figure 6.14, there seems to be a difference in the methods chosen to transfer knowledge on sustainable construction according to the age group. The oldest age group (55-65) seems to prefer using drawings, direct conversation, team meetings and phone than more IT related methods. The age groups 16-24, 25-34 and 35-45 use all of the nine methods. Hence this finding indicates a link between 'age group' and the choice of KT methods. As presented in section 3.4.2.5, Riege (2005) states that the age differences of participants in a KT can enhance or inhibit it. The findings show that this could be due to for instance preferring to use different methods to transfer knowledge.

Figure 6.15 below displays the cross tabulation between 'job level' and the chosen methods to transfer knowledge. As argued in section 6.2.2.2 there is a strong link between 'educational background' and 'job level'. As a result the cross tabulation 'job level' also stands for 'educational background'.

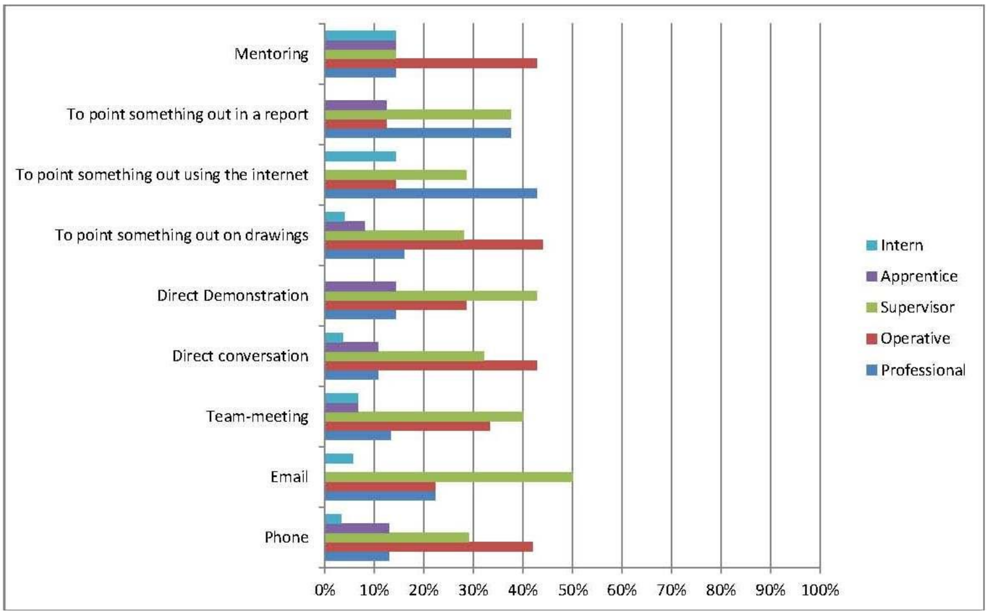


Figure 6.15: Knowledge Transfer Methods Cross Tabulation with Job Levels in Case Study UK1

Figure 6.15 suggests a difference in KT methods between the various construction workforce members according to their job level. Operatives and apprentices seem to rather prefer the following methods to transfer knowledge on sustainable construction:

- mentoring
- to point something out on drawings
- direct demonstration
- direct conversation
- team meeting
- phone

Professionals seem to prefer:

- to point something out in reports
- to point something out in the internet
- to point something out on drawings

An interesting result is that the operatives' supervisors seem to use nearly all methods at the same level. This might be due to them acting as an interface between professionals and operatives. In terms of testing the conceptual framework in practice, these findings might suggest to divide the KT methods by job level. Yet, it will be further explored in the other case studies whether this issue re-occurs. Section 3.4.2.5 presented that the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which could also inhibit KT.

In the previous section 6.2.3.6 the following five actors were identified as perceived experts on sustainable construction with the highest in-degree centrality. It was considered important to examine their choice of KT methods further.

- Elec4, supervisor → phone, email, direct conversation, team meeting
- BMS2, supervisor → phone, email, direct conversation, drawings, report, book, mentoring
- CM5, professional → n. a.
- BW3, supervisor → phone, email, direct conversation, team meeting, demonstration, drawings, report, routines
- BMS1, operative → phone, direct conversation, drawings

This shows that more central actors prefer similar KT methods. Moreover their choice of KT methods is according to their job level, i.e. in line with the results for the overall job levels presented in Figure 6.15. As a result this leads to the assumption that the link between KT methods and ‘job level’ seems to be stronger that the one with actor centrality.

6.2.4. Conclusion

This section presented the data analysis of the first UK case study. It first provided a brief overview of the research settings and the general actor attribute of the research participants. Thereafter it was investigated to what extent the actor attributes and social network characteristics relate to each other and influenced the knowledge transfer on sustainable construction in this case study.

Table 6.19: General Factors and Social Network Characteristics influencing KT on sustainable Construction in Case Study UK1

	Awareness	Perceived Use of sustainable Material/ Technology	Training Received	Perceived Training Need	KT Methods	KT Source	Network Density	Job Level	Age
Age	x	x	√	x	√	x	n/a	n/a	n/a
Gender	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Nationality	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Education	Linked to job level								
Job level	√	√	√	x	√	√	n/a	n/a	n/a
Tie Contents	n/a	n/a	n/a	n/a	√	NP	√	√	n/a
Actor Centrality	√	NP	x	x	x	√	n/a	√	x
Awareness	n/a	x	n/a	n/a	n/a	√	n/a	√	x

√ - linked; x – not linked; NP – link not prominent enough; n/a – not applicable/ investigated

In summary the analysis carried out in this case study seems to suggest that a number of factors may broadly influence each other and KT on sustainable construction. Table 6.19 provides an overview of the findings, which will be explained in the succeeding paragraphs.

In relation to so-called general influencing factors (please see section 5.3.2 for more details), such as gender and nationality, no remarkable results have been detected due to the nature of the sample, i.e. participants were mostly male and British. However, as stated in section 3.4.1.1 this result might not fully represent the multi-cultural background of some respondents. Moreover the finding in section 6.2.2.2 confirmed that education defines job level later in life, hence these two actor attributes are linked. As a result succeeding analyses were conducted for job level only, but represent the variable educational background as well.

The age group of the research participants did not influence the awareness, the perceived use of sustainable materials or the training needs. However, a link between age group and received training was detected in section 6.2.2.5. Out of all respondents only 20.5% stated that they have had special training on sustainable construction. Yet, 38.7% of those who have not received training on sustainable construction are of the age group 25-34. As sustainability in the built environment is a well-discussed subject and emerged over the past two decades, these numbers might indicate that this has not yet been implemented enough in education/ vocational training.

The actor attribute job level has had the most influence on other variables in this case study. The research participants, who were not aware of the sustainability target of this project, were only to be found in the construction workforce, i.e. operatives, apprentices and their supervisors. The same was the case regarding the use of sustainable materials/ technologies. This indicates a clear link between job level and awareness, and suggests better informing the construction workforce in order to raise their awareness. Nevertheless of those, who actually received specialised training, 87.5% were operatives and supervisors. Thus it appears as if the suggested training is already taking place. Moreover this indicates a clear link between job level and received training as well. In addition the findings showed a general lack of agreement whether special sustainability training is necessary and what it actually involves.

In regards to the social network characteristics, the network density was found to be rather low with a value of 0.03. This indicates a sparse network with not much KT on sustainable construction occurring in this construction project. However, when examining the tie content it was found that both tacit and explicit knowledge were transferred through this rather sparse network. In fact tacit knowledge was part of 55.2% of all occurred KTs. In addition, the link between tie contents and KT methods, asserted in the literature was confirmed, as the most frequently used KT methods proved the transfer of tacit knowledge. As discussed in section 4.4.1 and 4.4.2, Granovetter (1973) and Reagans and McEvily (2003) argue that the tie characteristic, i.e. strength or weakness, determine the type of knowledge that is transferred. Therefore this finding proves that it might be a sparse network but with rather strong ties which facilitated the transfer of this large amount of tacit knowledge. Hence this issue questions literature and will be observed in the other case studies.

Centrality measures showed which actors are perceived as experts on sustainable construction by others and which only consume knowledge. Here supervisors and professionals were perceived as experts, whereas operatives were mostly knowledge consumers. As a result there seems to be a link between actor centrality and job level, as expected. As already argued in Chapter 2, specialist knowledge and thus specialists are required to deliver sustainable office buildings. The findings imply that this is becoming the case, because supervisors of sub-contractors are regarded as experts. Moreover the findings indicate a relationship between tie contents and job levels, as knowledge on certain subject areas was required more frequently by certain job levels. As a result this suggests providing a knowledge flow that is more target-orientated to job levels, if this phenomenon reoccurs in the other case studies.

Additionally actors with a high in-degree centrality i.e. perceived experts showed more awareness of sustainable construction, although they did not all receive special training or felt the need for such training. Hence no link between actor centrality and training was detected. The main implications of this are to improve training on sustainable construction for supervisors, as operatives seem to largely depend on them. Moreover training for operatives should be offered.

In regards to the relationships to knowledge sources, colleagues (72) were more frequently consulted for advice on sustainable construction than managers (39) and supervisors (30), as there might be more trust based relations amongst them, than with someone from a superior job level. This is followed by colleagues from other companies involved in the same project (31). This finding is rather surprising, as it was assumed that due to the silo-based structure of the industry in which projects are organised along disparate disciplinary boundaries, argued by literature (e.g. WBCSD, 2008) there would be no significant link between various participating companies. Yet the network structure presented in Figure 6.11 confirmed the relatively good cooperation between the involved trades mainly through the construction management company. Nonetheless this observation could only be the case in the context of KT on sustainable construction during construction phase.

All KT methods of the conceptual framework were used. There was a link between the preferred KT methods and age group. As presented in section 3.4.2.5, Riege (2005) states that the age differences of participants in a KT can enhance or inhibit it. The findings show that this could be due to for instance preferring different methods to transfer knowledge.

Furthermore there is a clear link between the choice of KT methods and job level. The operatives' supervisors seem to use nearly all methods, while the construction workforce and professionals used different ones, i.e. professionals preferred more IT related KT methods and operatives more direct ones. This might be due to the supervisors acting as an interface between professionals and operatives. These findings might suggest arranging the KT methods in the conceptual framework by job level, if this phenomenon reappears in the other case studies. Section 3.4.2.5 presented that the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which could also inhibit KT.

Additionally the findings showed that most central actors do not use different or more methods than others, but rather according to their job level. Therefore there seems to be no link between actor centrality and KT methods in this case study.

The next part of this chapter presents the analysis of the second UK case study.

Key for Case Study UK1

indicates research participants

Trade	Code	Job Level	Code
Construction manager	CM	Intern	CM1
		Professional	CM2
		Professional	CM3
		Professional	CM4
		Professional	CM5
		Professional	CM6
		Professional	CM7
Dry Lining	DL	Supervisor operatives	DL1
		Operative	DL2
		Operative	DL3
		Professional	DL4
		Operative	DL5
		Operative	DL6
		Professional	DL7
Metall Ceilings	MC	Operative	MC1
		Supervisor operatives	MC2
		Operative	MC3
		Operative	MC4
		Professional	MC5
		Professional	MC6
		Professional	MC7
		Operative	MC8
		Operative	MC9
Building Management Systems	BMS	Operative	BMS1
		Supervisor operatives	BMS2
		Operative	BMS3
		Professional	BMS4
		Supervisor operatives	BMS5
		Operative	BMS6
		Operative	BMS7
		Operative	BMS8
		Operative	BMS9
		Professional	BMS10
		Operative	BMS11
		Operative	BMS12
Fire Alarms	FA	Operative	FA1
		Operative	FA2
		Supervisor operatives	FA3
		Professional	FA4
Brickwork	BW	Operative	BW1
		Operative	BW2
		Supervisor operatives	BW3
		Professional	BW4
		Professional	BW5
Mechanical Contractors	Mec	Operative	Mec1
		Supervisor operatives	Mec2
		Operative	Mec3
		Supervisor operatives	Mec4
		Supervisor operatives	Mec5
		Professional	Mec6
		Professional	Mec7
		Professional	Mec8
		Operative	Mec9
		Operative	Mec10
		Professional	Mec11
		Professional	Mec12
		Professional	Mec13
		Professional	Mec14
		Professional	Mec15
		Professional	Mec16
		Professional	Mec17
		Professional	Mec18
		Professional	Mec19
Electrical Contractors	Elec	Apprentice	Elec1
		Operative	Elec2
		Apprentice	Elec3
		Supervisor operatives	Elec4
		Operative	Elec5
		Operative	Elec6
		Professional	Elec7
		Professional	Elec8
		Operative	Elec9
Fire Stopping Contractors	FS	Operative	FS1
		Operative	FS2
Stonework	St	Supervisor operatives	ST1
		Operative	ST2
		Operative	ST3
		Professional	ST4
		Supply chain member	ST5
		NA	ST6
		Operative	ST7
		Operative	ST8
		Operative	ST9
Commercial WC & joinery Fit-Out	FO	Apprentice	FO1
		Operative	FO2
		Supervisor operatives	FO3
		Operative	FO4
		Operative	FO5
		NA	FO6
		Operative	FO7
		Operative	FO8
		Professional	FO9
Architect	Arc	Professional	Arc1
		Professional	Arc2
		Professional	Arc3
		Professional	Arc4
		Professional	Arc5
		Professional	Arc6
		Professional	Arc7
		Professional	Arc8
		Professional	Arc9
		Operative	Arc10
		Operative	Arc11
		Operative	Arc12
Services Engineer	SE	Professional	SE1
		Professional	SE2
		Professional	SE3
		Professional	SE4
		Professional	SE5
		Professional	SE6
		Professional	SE7
		Supply chain member	SE8
Structural Engineer	Str	Professional	Str1
Cost Consultant	CC	Professional	CC1
		Professional	CC2
		Professional	CC3
		Professional	CC4
		Professional	CC5
		Professional	CC6
		Professional	CC7
Logistics	Log	Professional	Log1
		Supervisor operatives	Log2
Developer	Dev	Professional	Dev1
Contacts outside the project	Soc	Friend of MC3	Soc1
		Friend of MC3	Soc2
		Father of BW2	Soc3
		Friend of FS1	Soc4

6.3. **Case Study UK 2 – London**

6.3.1. Research Setting

The construction project of this approximately 51,100 square meters large prime office scheme was located in East London and carried out by a main contractor. Project completion was planned for Mid-2014. The project targeted an 'excellent' BREEAM rating and an Energy Performance Certificate rating of 40 or better.

The project was aiming to achieve the following scores in the eight main criteria groups of the BREEAM certificate, as presented in section 2.4.2.

Table 6.20: Sustainable Performance of Project UK2

Criteria Groups	**Credits**	**Weighted Section**
Management	10	12.0%
Health	8	9.2%
Energy	12	9.9%
Transport	10	8%
Water	5	5%
Materials	5	4.8%
Land Use & Ecology	9	9%
Pollution	10	8.3%
Total	**69**	**71.64%**

Construction started in February 2012, thus the project was in a very early stage at the time of data collection. A total of 11 questionnaires and a small set of participant observation data were mainly collected in an on-site office.

6.3.2. Actor Attributes

This section presents the actor attributes of the research participants and their relationships, if any.

6.3.2.1. Age, Gender and Nationality

Figure 6.16 shows that the age range of the research participants in this case study was very diverse, with 18.2% in each of the three age groups between 16 and 24, 25 and 34, and 35 and 44. 45.5% of the participants were between 45 and

54, but none between 55 and 64. As illustrated in Figure 6.17 most respondents were male (90.9%). In addition, practitioners from four different countries participated in this research, i.e. UK (63.6%), Ireland (18.2%), Australia (9.1%) and Italy (9.1%) (see Figure 6.18). Since most participants were British and male, no remarkable results were found in cross tabulations with these variables. Yet, as indicated in section 3.4.1.1 this result only reflects the actual citizenships of the respondents and not their potential multi-cultural background. As a result age group was singled out of these three variables for succeeding analyses.

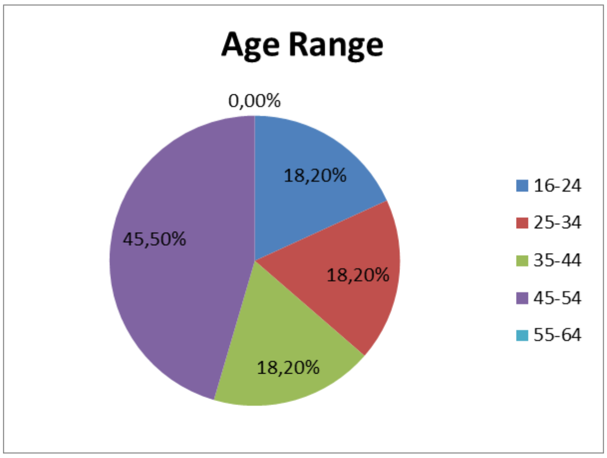


Figure 6.16: Age Range of Research Participants in Case Study UK2

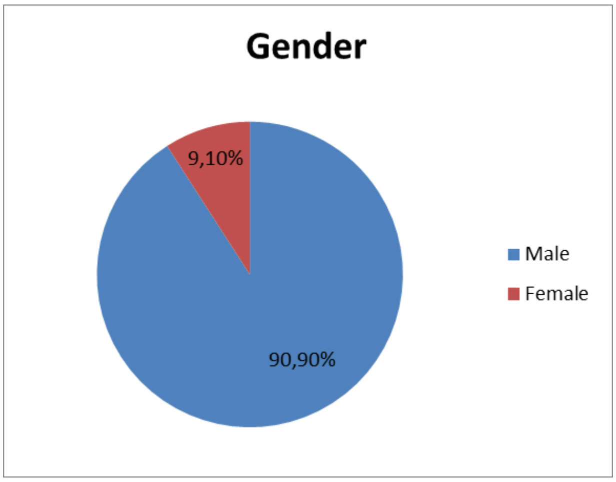


Figure 6.17: Gender of Research Participants in Case Study UK2

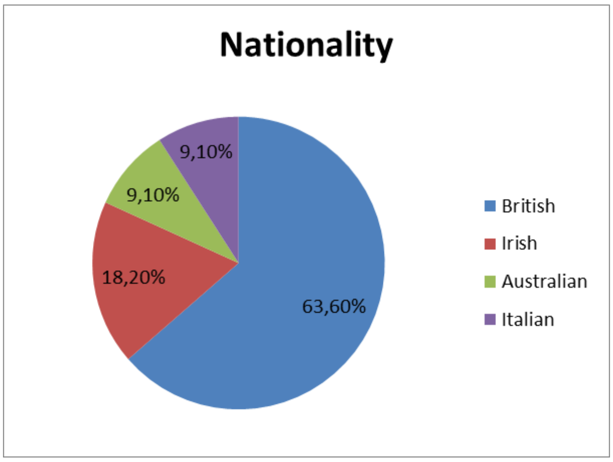


Figure 6.18: Nationality of Research Participants in Case Study UK2

6.3.2.2. Educational Background and Job Levels

The educational background of the research participants, presented in Figure 6.19 varied from 9.1% with no education or job training, 36.4% had completed an apprenticeship, 36.4% a Bachelor's degree, and 18.2% a Master's degree. As illustrated in Figure 6.20, this case study included participants from only three job levels, i.e. interns (9.1%), operatives' supervisors (36.4%) and professionals (54.5%). No operatives participated in this case study.

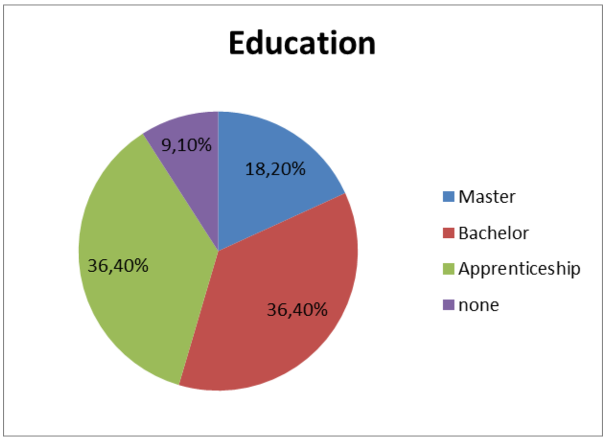


Figure 6.19: Educational Background of Research Participants in Case Study UK2

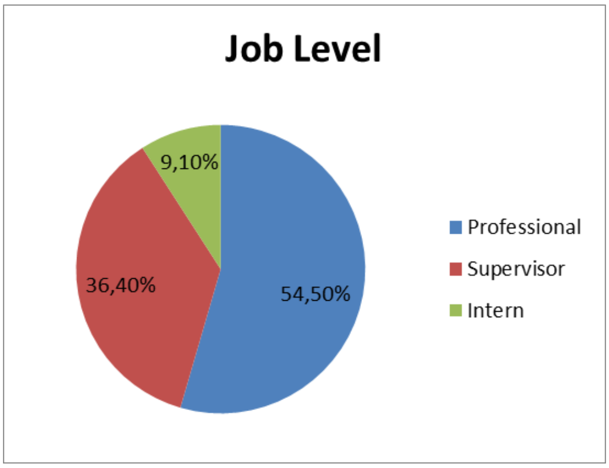


Figure 6.20: Job Level of Research Participants in Case Study UK2

Table 6.21 confirms the strong relationship between ‘educational background’ and ‘job level’, as expected. As a result the succeeding analyses in this case study will equate educational background and job level. Thus bivariate analyses conducted for job level only stand for both variables.

Table 6.21: Cross Tabulation between educational Background and Job Level in Case Study UK2

	Job Level			**Total**
Educational Background	Professional	Supervisor	Intern	
None	0	1	0	1
Apprenticeship	1	3	0	4
Bachelor	3	0	1	4
Master	2	0	0	2
Total	6	4	1	11

6.3.2.3. Awareness of Sustainability

Figure 6.21 shows that 72.7% of the respondents in this case study were aware that this construction project strived to achieve a BREEAM certificate. This finding is supported by a statement of one respondent, who said that he/she has the impression that the ‘*general understanding of sustainability and methods to attain the BREEAM score, using sustainable materials and services appears to be very good in this construction project*.’ This result can be considered as rather high, compared to the other case studies, but might be due to the fact that no operatives and apprentices took part in this case study. Hence the nature of the sample regarding job levels might have affected the outcome.

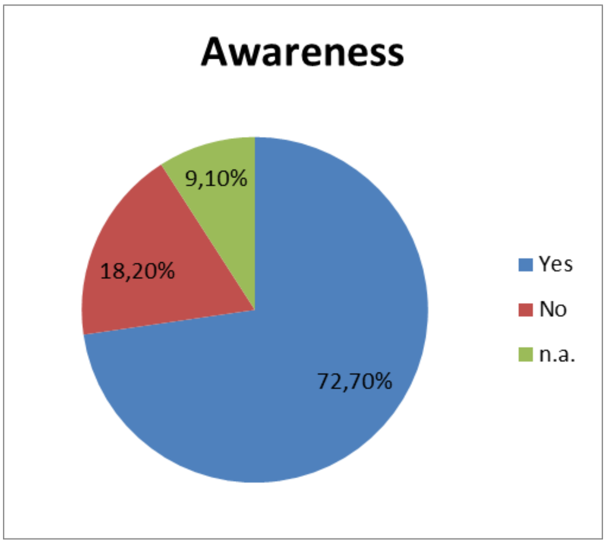


Figure 6.21: Awareness of Sustainability of Research Participants in Case Study UK2

When investigating this matter further it was found that levels of awareness of sustainability are spread throughout the various age groups (see Table 6.22). Hence it is clear that there is no link between these two variables, i.e. age does not affect awareness.

Table 6.22: Cross Tabulation between Awareness and Age Group in Case Study UK2

	Awareness			**Total**
Age Group	**Yes**	**No**	**Not ticked**	
16-24	1	1	0	2
25-34	1	0	1	2
35-44	1	1	0	2
45-54	5	0	0	5
Total	8	2	1	11

Table 6.23 shows that there were only two research participants, who were not aware of the sustainability target of this project, one professional and one supervisor. Thus this finding suggests there is no link between ‘job level’ and ‘awareness of sustainability’ in this case study. As mentioned before this result could have been influenced by the small sample size and that no operatives took part in this case study.

Table 6.23: Cross Tabulation between Awareness and Job Level in Case Study UK2

	Awareness		Total
Job Level	Yes	No	
Professional	4	1	5
Supervisor	3	1	4
Intern	1	0	1
Total	8	2	10

6.3.2.4. Perceived Use of Sustainable Materials and Technologies

Figure 6.22 presents the replies to the question whether the research participants were aware, if their companies use some kind of sustainable material or technology. 90.9% of the answers were positive. Here it is interesting that 18.2% more respondents were aware of them using some kind of sustainable material or technology within their own company, but did not necessarily connect this with the overall aim of the project to achieve a sustainability certificate (see Figure 6.21 in the previous section).

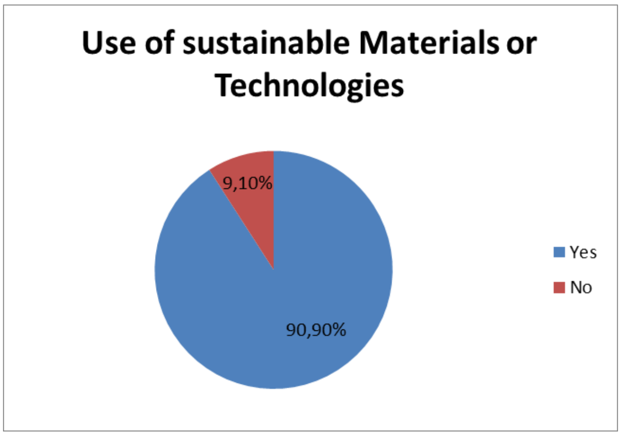


Figure 6.22: Perceived Use of sustainable Materials/ Technologies of Research Participants in Case Study UK2

One supervisor of construction operatives criticized that '*more explanations are needed on why [certain materials are to be used], especially for the construction workforce. The design team makes decisions and doesn't give any explanations to the construction team.*' Another research participant put forward that *'sustainability is a design process only and has nothing to do with construction.'* Moreover one supervisor stated that *'there is no knowledge transfer between surveyors and construction.'* Thus these comments support the point of view that there is awareness of using a sustainable product, but not necessarily of the reasons why this is done. Moreover they indicate a gap in the knowledge flow between the design and the construction stage of the project, as argued by Wallbank and Price (2007). It would have been helpful, if operatives participated in this research to further investigate these statements. However, as a result the following cross tabulation in Table 6.24 shows no relationship between the 'perceived use of sustainable materials' and 'job level' for the three job levels represented.

Table 6.24: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Job Level in Case Study UK2

	Perceived use of sustainable materials and technologies		Total
Job Level	**Yes**	**No**	
Professional	6	0	6
Supervisor	3	1	4
Intern	1	0	1
Total	10	1	11

The cross tabulation depicted in Table 6.25 shows that there is also no link between the 'perceived use of sustainable materials' and 'age' in this case study.

Table 6.25: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Age in Case Study UK2

	Perceived use of sustainable materials and technologies		Total
Age Groups	**Yes**	**No**	
16-24	2	0	2
25-34	2	0	2
35-44	1	1	2
45-54	5	0	5
Total	10	1	11

The respondents elaborated further on their use of sustainable materials and technologies, which was analysed using content analysis, as described in section 5.6.3. The results are summarised in Table 6.26. This data derives only from the respondents, who elaborated further on this topic. Thus the percentage of 'no use of sustainable materials' (18.18%) does not match with the replies on 'companies' use of sustainable materials and technologies' (9.1%) in Figure 6.22.

Table 6.26: Perceived Use of sustainable Materials/ Technologies of Research Participants in Case Study UK2

Code	Count	Percentage
Do not use sustainable material	1	9.09%
No usage because professionals	1	9.09%
timber / wood (FSC rating)	4	36.36%
Waste control	3	27.27%
Solar panels / PV	2	18.18%
Rainwater harvest system	2	18.18%
Under floor heating	2	18.18%
Green guide rated concrete and BE56001 certified	1	9.09%
Green roof	1	9.09%
Developed paperless system on a smart phone app	1	9.09%
Hot water heating system	1	9.09%
Low energy lighting	1	9.09%
Mx Machines (electric motor)	1	9.09%

The materials and technologies named by research participants are for the most part in fact sustainable. Some confusion exists only for under-floor heating and MX machines. This suggests that amongst those research participants who elaborated on this matter, there is a very high level of understanding and awareness about sustainable materials and technologies.

The cross tabulation in Table 6.27 examines the link between 'awareness' and 'perceived use of sustainable materials/ technologies' further. Out of 11 research participants only one was not aware of the sustainability target and also indicated no use of sustainable materials/ technologies. Nonetheless, this is not statistically valid as a statement due to the small sample size.

Table 6.27: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Awareness in Case Study UK2

	Perceived use of sustainable materials and technologies		Total
Awareness	**Yes**	**No**	
Yes	8	0	8
No	1	1	2
Not ticked	1	0	1
Total	10	1	11

6.3.2.5. Received and Required Training on Sustainable Construction

Figure 6.23 illustrates the received training on sustainable construction, while Figure 6.24 presents the perceived requirement for such training.

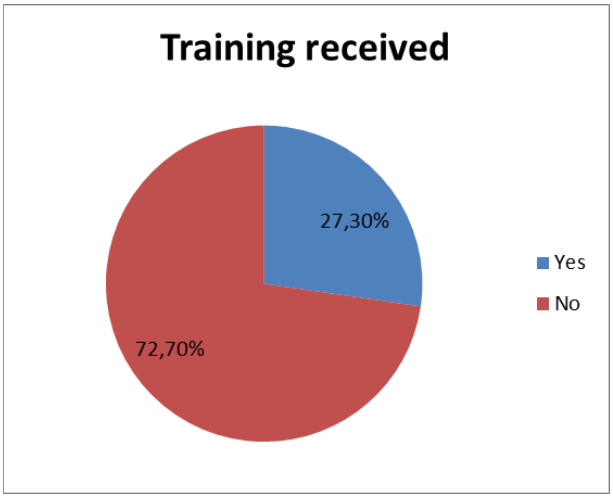


Figure 6.23: Received Training on sustainable Construction of Research Participants in Case Study UK2

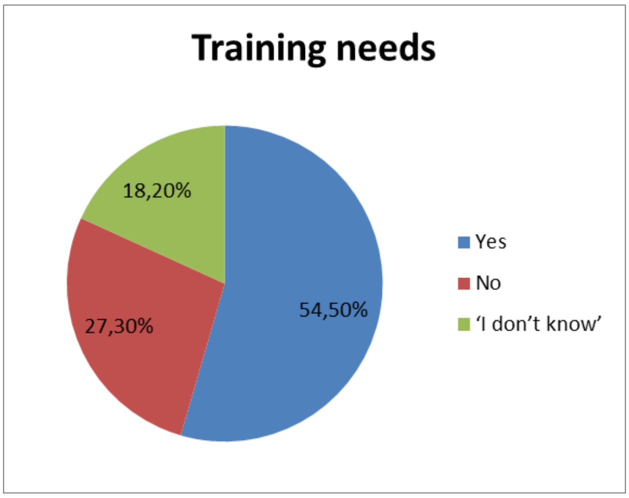


Figure 6.24: Perceived Requirement for Training on sustainable Construction of Research Participants in Case Study UK2

Out of all respondents only 27.3% stated that they have had a special training on sustainable construction, while 54.5% acknowledged the requirement of such specific skills. This means only half of the respondents, who feel they require such training actually received it. This finding is supported through qualitative questionnaire data, where four out of 11 respondents mentioned a lack of training on sustainable construction. They especially requested in-house or on-the-job training to help them understand sustainable construction better.

Nevertheless two respondents elaborated further on why they do not feel they require special training: '*there is no difference between conventional and sustainable construction*' and *'there is no difference in putting sustainable timber to normal one.'* This point of view was generally very often observed while carrying out data collection in all five case studies.

It was considered to be vital to further investigate whether the variables 'age group' and 'job level' affect the training received and required.

Table 6.28: Cross Tabulation between received Training and Age Group in Case Study UK2

	Received training		**Total**
Age Group	Yes	No	
16-24	0	2	2
25-34	0	2	2
35-44	0	2	2
45-54	3	2	5
Total	3	8	11

Table 6.29: Cross Tabulation between Training Needs and Age Group in Case Study UK2

	Perceived training needs			**Total**
Age Group	**Yes**	**No**	**'I don't know'**	
16-24	1	0	1	2
25-34	2	0	0	2
35-44	0	1	1	2
45-54	3	2	0	5
Total	6	3	2	11

As depicted in Table 6.28 it is evident that the majority of research participants who did not receive any special training are within various age groups. However, the only three participants who received training on sustainable construction are all of the same age group, i.e. 45-54. Hence there seems to be a moderate link between 'age group' and 'received training' in this case study. As sustainability in the built environment is a well-discussed subject and emerged over the past two decades, these participants had most likely already finished their job training, when this subject was introduced to the curriculum. Therefore their training was most likely on-the-job. This is also confirmed by various statements on trainings, summarised in Table 6.32 and the respondents' comments from the previous paragraphs.

Moreover 27.3% of the research participants did not consider such training necessary (see Figure 6.27) and were spread across the different age groups, as shown in Table 6.29. Hence age does not influence training issues in this case study.

Table 6.30: Cross Tabulation between Job Level and received Training in Case Study UK2

	Received training		**Total**
Job Level	**Yes**	**No**	
Professional	2	4	6
Supervisor	1	3	4
Intern	0	1	1
Total	3	8	11

Table 6.31: Cross Tabulation between Job Level and Training Needs in Case Study UK2

	Perceived training needs			**Total**
Job Level	Yes	No	'I don't know'	
Professional	3	2	1	6
Supervisor	2	1	1	4
Intern	1	0	0	1
Total	6	3	2	11

The majority of respondents in this case study (72.7%) did not receive any specialised training on sustainable construction and they are wide-spread throughout the various job levels, as depicted in Table 6.30. Nevertheless this cross tabulation shows that the intern did not receive any special training on sustainable construction, which seems strange as this should be part of his/her university education.

Table 6.31 presents a wide range of answers in relation to the question whether such training is actually required. Hence no link with job levels was detected. Nonetheless this shows a general lack of agreement as to the necessity of such training.

In order to explore the issue of training and skills on sustainable construction further, the research participants were asked to elaborate further on the question what kind of training they received. This was analysed using content analysis, as described in section 5.6.3. This data only derives from respondents who elaborated further on this topic. The results are presented in Table 6.32.

Table 6.32: Perceptions of sustainable Construction Training in Case Study UK2

Code	Count	Percentage
I had no training	8	72.72%
The materials do not need any special skill, as they are very similar to any non-sustainable material	2	18.18%
CPD (continuing professional development) courses	2	18.18%
On-the-job training	1	9.09%
1 day course in-house	1	9.09%
I was not employed when in-house course was on	1	9.09%
I had no training, because I'm only employed for a short period of time	1	9.09%
I did not know about it	1	9.09%
Post project reviews	1	9.09%
Company training required for various products	1	9.09%
General training to raise awareness	1	9.09%
Workshops with specialist consultants	1	9.09%
Training by manufacturer	1	9.09%
Sustainable design is delivered with specialist consultants / sub-contractors	1	9.09%
Project Manager Development discussions/ forums	1	9.09%
CSCS, SMSTS, SWAMP, First Aid	1	9.09%
I had no special training but over 20 years of industry background	1	9.09%
I had special training to formalise my knowledge – get a certificate	1	9.09%

Table 6.32 shows that some of the perceptions of training on sustainable construction are simply wrong, for instance a First Aid course. This might lead to the conclusion that some research participants simply listed any training they have ever received, without differentiating whether it was on sustainability. This can be explained by the lack of training indicated by 72.7%. Nevertheless, some of the answers imply that the construction management company at this project does offer in-house courses. However, as two respondents further elaborated, '*it seems to be only for employees on permanent contracts'* and *'only every now and then'.*

The statement in Table 6.32 about '*sustainable design is delivered with specialist consultants / sub-contractors'* is in line with the literature (Rohrbacher, 2001) that such projects require more specialised companies, as argued in Chapter 2.

Some of the statements in Table 6.32 do concern how participants did receive their knowledge on sustainable construction and are hence about KT methods. These are hence particularly significant in terms of testing the conceptual framework in practice.

- CPD (continuing professional development) courses
- On the job training
- 1 day course in-house
- Post project reviews
- Training by manufacturer
- Workshops with specialist consultants

Five of these six knowledge transfer methods above were already part of the KT process box of the conceptual framework presented in section 5.3.2. Hence in terms of testing the conceptual framework in practice, these statements were taken into account. Moreover, workshops with specialist consultants could be allocated to e.g. adult learning. Furthermore it was investigated whether the findings of the other case studies confirm this trend.

The next section examines the social network characteristics, their relationships and to what extent they influenced KT on sustainable construction.

6.3.3. Social Network Characteristics

Figure 6.25 presents the knowledge network of this case study. The colour coding and line weights used are in accordance with the description provided in section 5.6.4. Please also see the key at the end of each case study for clarification of figures within this chapter.

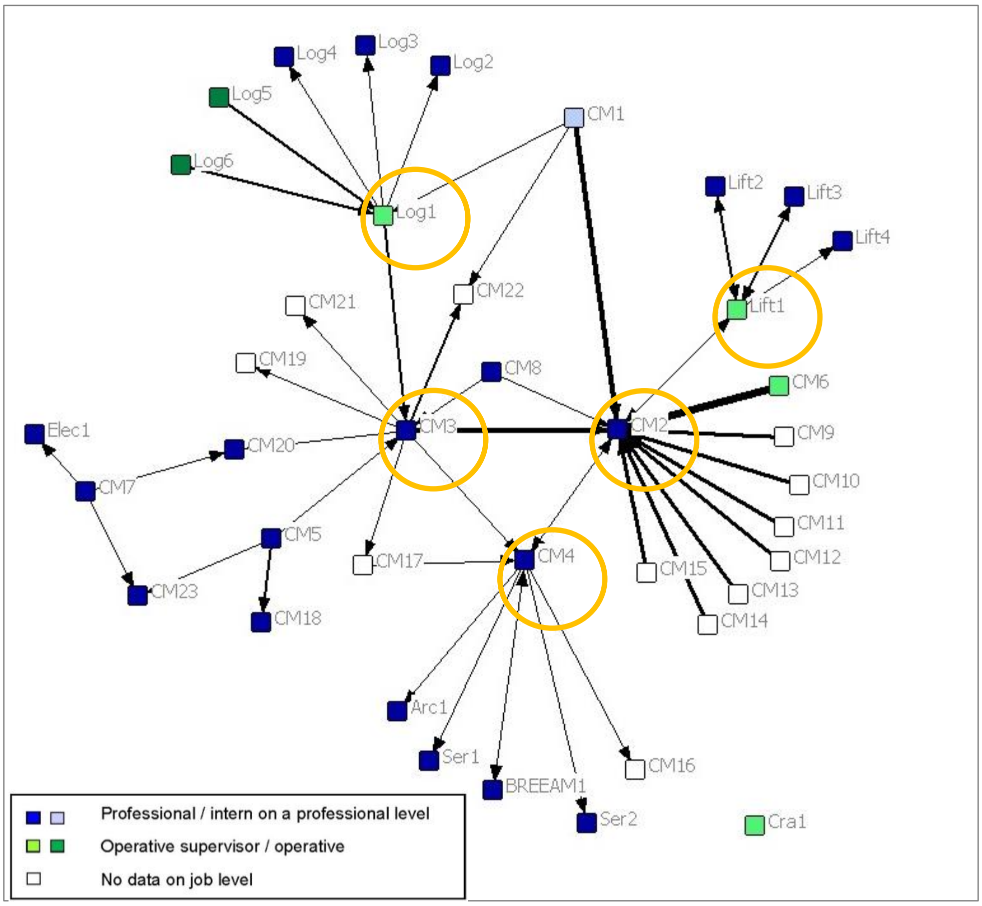


Figure 6.25: Knowledge Transfer Network of Case Study UK2

6.3.3.1. Size of the Network

This network comprises of 39 nodes and is much smaller than the UK1 case study. As you can see in the fold-out key at the end of this case study, only 11 out of the 39 were research participants. The other 28 actors were named by them. Nevertheless, all of the 39 were involved in the same project or participating companies. As stated in section 5.5.2.1 the network boundary was defined as all participants on one particular sustainable office construction project. The sampling, which led to these 11 research participants is presented in section 5.4.2. Section 9.4 – Limitations explains further why it was not possible to include operatives or apprentices in this case study.

6.3.3.2. Network Structure

The network structure consists of one component and one isolate, i.e. Cra1 on the bottom of Figure 6.25. Cra1 filled in the questionnaire, but left the SN questions blank and no one named him as a knowledge source on sustainable construction. This might be due to his/her job role as being responsible for the on-site cranes, which does not require any interaction with other participants regarding KT on sustainable construction.

The main component includes the following companies: construction management, elevators/ lifts, logistics, architects, service consultants, BREEAM assessor and electrical consultant.

6.3.3.3. Cut-points and Hierarchy Levels

There are only a few cut-points in this social network, indicated with orange circles in Figure 6.25. Please see section 4.4 for the definition of cut-points.

The major cut-points are Log1, Lift1, CM2, CM3 and CM4. While Log1, Lift1, CM2 and CM3 function as interfaces towards their immediate work team, CM4 interlinks with actors from various companies. This outcome is somewhat unexpected. CM4 is the architectural design manager, which might explain his/her network position. He/she transfers and receives knowledge on all three subject areas.

CM2 is the sustainability manager of this project. Thus it could have been assumed that CM2 is more interlinked to various companies which is not the case. This could be because CM2 is employed by the construction management company. Moreover all ties are directed towards CM2, which means that the actors ask him for advice on sustainable construction and he/she hardly requires advice. This confirms CM2 being an expert on sustainable construction. Yet he/she is also employed for this reason. In addition the ties linked to CM2 are thicker than most of the other ties in the network. As stated in section 5.6.4 the line weight expresses the frequency of KT, i.e. a thicker the tie means more frequent KT. Thus this finding shows that the project participants make good use of the fact that a sustainability manager is employed for this construction project. This is in line with literature, as Thomson *et al*. (2010) suggest the employment of a sustainability expert to facilitate the flow of knowledge.

CM3 is the project manager in charge. He/she requests knowledge mainly on sustainable technologies and gives knowledge on sustainable materials only. Furthermore CM3 is only linked to employees of the construction management company and the logistics. Yet this could be due to the early construction stage the project was in at the time of data collection.

It is very difficult to make a statement regarding the hierarchy levels in this social network, as there is no data on the job level for 13 nodes. In addition to this, it was not possible to include operatives and apprentices as research participants. Therefore the only two operatives in this network are Log5 and Log6, who were named by Log1.

6.3.3.4. Relationship between Network Density and Tie Characteristics and Tie Contents

The network density is 0.0628 with a standard deviation of 0.4402. This value indicates a mean strength of all possible ties of 0.06, i.e. 6% of all possible ties are present in this network (Hanneman and Riddle, 2005). As discussed in Chapter 4 the maximum value would be 1.0, i.e. 100% of all possible ties being present. 0.06 is a very low value, implying that this network is rather sparse than cohesive. Although the density value is double the density value of case study UK1, this is most likely due to the smaller size of the network, i.e. lower number of nodes (ibid). The standard deviation is larger than the mean, which indicates a great variation in the strength of ties.

As argued in section 6.2.3.4, it is vital to explore the nature of transferred knowledge further in order to prove how the tie contents, tie characteristics and network density relate to each other in this case study. Moreover result could indicate what kind of knowledge is required more and by which workforce group. Please see section 3.2 and 5.3.1 for a detailed definition on the three subject areas regarding sustainable construction and the knowledge types. Table 6.33 presents an overview of the frequencies of the various tie contents of the 51 knowledge transfers on which research participants provided data.

Table 6.33: Tie Contents of Knowledge Transfers in Case Study UK2

Tie Content	Knowledge Type	Frequency Count	Valid Percentage
All: Materials, Technologies and Techniques	Explicit and tacit	22	43.14%
Technologies	Explicit and tacit	7	13.73%
Materials	Explicit	5	9.8%
Materials and Techniques	Explicit and tacit	4	7.84%
Materials and Technologies	Explicit and tacit	4	7.84%
Techniques	Tacit	2	3.92%
Technologies and Techniques	Explicit and tacit	2	3.92%
No data on tie content	-	5	9.8%

As shown in Table 6.33, the most discussed subject by far is a combination of all three subject areas (materials, technologies and techniques) (43.14%). This finding was partially expected, as it was argued in section 5.3.1 that new sustainable materials and technologies might need adjusted or new techniques for their correct installation. As a result many questions might evolve around new materials/ technologies and techniques on how to put them together. Hence this finding supports this argument.

The discussed subject areas give further indications to the knowledge types transferred and therefore can be linked back to the tie characteristics and the network density. As mentioned above the most discussed subject area by far was materials, technologies and techniques combined. In the main, the knowledge on materials and technologies is explicit. However, the new knowledge on techniques was defined as fully tacit. Hence a combination of all three subject areas represents a combination of tacit and explicit knowledge. As a result tacit knowledge was part of 58.82% of the transferred knowledge through this rather sparse network. Therefore the rather large amount of transferred tacit knowledge is an interesting finding and similar to case study UK1. It was argued in section 4.4.2 that strong ties defined by trust and close relationships ease the transfer of tacit knowledge (Granovetter, 1973; Augier, Vendelø, 1999). Therefore the findings on knowledge sources in section 6.3.3.7 will prove whether the ties in this rather sparse network are strong and thus explain such a large amount of transferred tacit knowledge.

6.3.3.5. Relationship between Tie Contents and the Actor Attribute Job Level

In order to determine whether knowledge on certain subject areas is more in demand by a particular workforce group, cross tabulation was carried out between tie content and the actor attribute 'job level'. The results are summarised in Table 6.34 and show the job level of the person who asked for advice on sustainable construction.

Table 6.34: Tie Contents of Knowledge Transfers linked with Actor Attribute Job Level in Case Study UK2

	No data on tie content	**Materials**	**Technologies**	**Techniques**	**Materials and Technologies**	**Materials and Techniques**	**Techniques and Technologies**	**All three subject areas**	**Total**
Operative	0%	100%	0%	0%	0%	0%	0%	0%	**100%**
Supervisor	9.09%	18.18%	0%	0%	27.27%	18.18%	0%	27.27%	**100%**
Intern	0%	0%	0%	0%	0%	0%	0%	100%	**100%**
Professional	14.81%	3.7%	25.93%	7.41%	3.7%	3.7%	7.41%	33.33%	**100%**

As shown in Table 6.34 the most discussed subjects for each job level were:

- Operatives → Materials
- Operatives' Supervisors → All three subjects; Materials and technologies
- Interns → All three subjects
- Professionals → All three subjects; Technologies;

This finding shows that the previously most discussed subject area (a combination of all three subject areas) was discussed by supervisors, professionals and the intern. This suggests that they are not only concerned about the 'what' in terms of new sustainable building materials or technologies, but also about the 'know-how', i.e. the correct installation, to achieve a good quality sustainable built result.

Furthermore Table 6.34 shows a slight difference in the demanded subject areas depending on the actor attribute 'job level'. Operatives seem to be only concerned about materials. Supervisors also request knowledge on sustainable materials and technologies and professionals on technologies. Therefore this suggests a link between tie contents and 'job level' of the actors involved in a KT.

6.3.3.6. Relationships between Centrality Measures and the Actor Attributes Job Level and Age

Similar to section 6.2.3.6 this section explores the centrality measures of the nodes in this knowledge transfer network. Figure 6.26 shows the same network map as Figure 6.25, but with different node sizes, representing the average degree centrality of the actors.

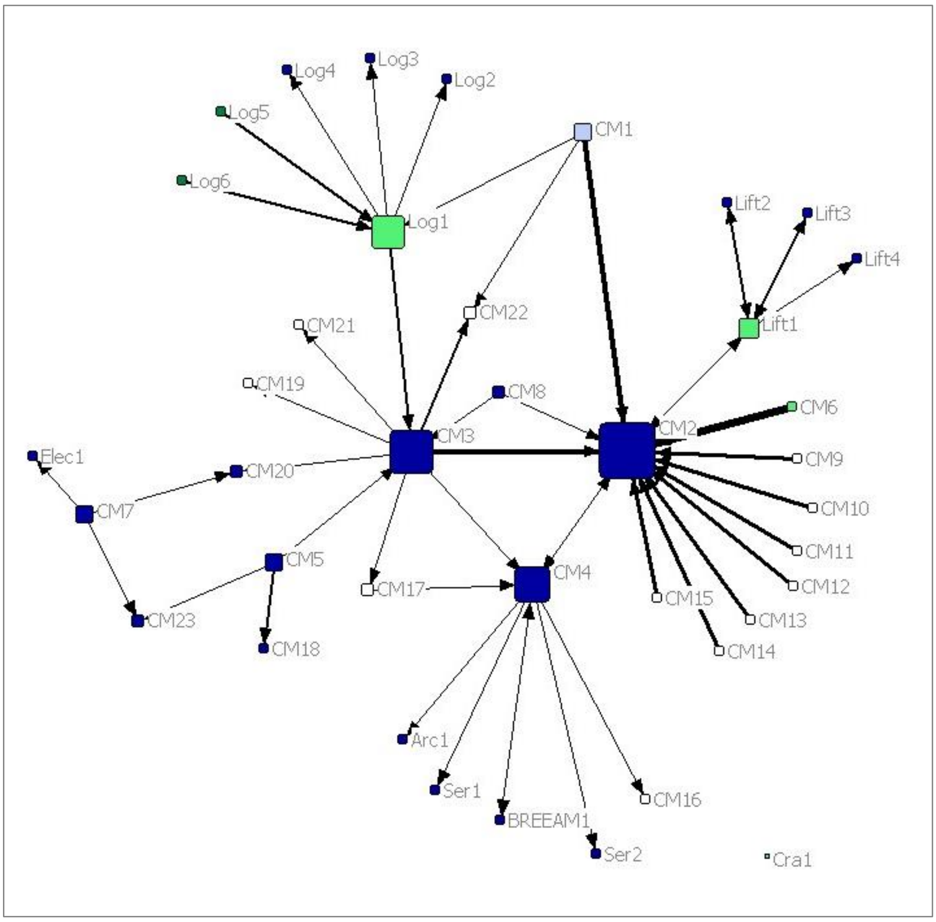


Figure 6.26: Knowledge Transfer Network of Case Study UK2 – Degree Centrality

In order to support Figure 6.26, Table 6.35 presents the five most central actors for in-degree and out-degree centrality and their respective other value.

Table 6.35: Centrality Measures in Case Study UK2

Actor	In-Degree	Actor	Out-Degree
CM2	49	CM3	13
Log1	5	CM6	8
CM3	4	CM1	7
CM4	4	CM4	6
Lift1	4	Lift1	6
CM6	0	Log1	5
CM1	0	CM2	2

It was considered important to examine whether the in- and out-degree values are linked with the actor attributes ‘job level’ and ‘age group’, as shown below.

Perceived experts:

- CM2, professional of the construction management company and sustainability manager of this project, age group: 35-44
- Log1, supervisor of the logistics company, age group: 45-54
- CM3, construction project manager in charge, age group: 45-54
- CM4, professional of the construction management company, age group: 45-54
- Lift1, supervisor of the lift company, age group: 45-54

Knowledge consumers or brokers:

- CM3, construction project manager in charge, age group: 45-54
- CM6, supervisor of the construction management company, age group: 45-54
- CM1, intern of the construction management company, age group: 16-24
- CM4, professional of the construction management company, age group: 45-54
- Lift1, supervisor of the lift company, age group: 45-54

First of all there seems to be a basic trend of the age group 45-54 being more represented within these central actors. However, this is probably only due to the nature of the sample, as 45.5% of the research participants are of this age group. Hence there is most likely no link between actor centrality and age group.

As previously mentioned CM2 is the sustainability manager on this project and with an in-degree centrality value of 49 definitely the most central person in this social network. He/she is perceived by far to be the expert, i.e. most knowledgeable person on sustainable construction in this project, as the in-degree centrality value is about ten times higher than of the other actors. This can be explained by him/her being employed for being knowledgeable on this subject. The knowledge he/she shares with the other project participants is on various combinations of all three subject areas to the same amount. Hence this finding is as expected as well. One research participant elaborated on this by stating *'very good knowledge of client environmental manager and his/her willingness to help and improve has been great so far.'*

The high centrality of the sustainability manager might indicate a change in traditional job roles. Before sustainability issues changed construction industry (Rohrbacher, 2001), it was rather the architect or construction project manager, who solely was in such a central position, but maybe in future this could be the sustainability manager or assessor as well. This goes along with Thomson *et al.* (2010) who suggested employing a sustainability expert to enhance the knowledge flow in a construction project.

Log1 could be asked a lot of questions on sustainable construction simply due to the job role, i.e. dealing with the logistics of this project. Hence it is not surprising that most KTs are on sustainable materials only.

It could have been assumed that the project manager in charge CM3 is regarded as a general expert not only on sustainable construction, but an over-all person to contact with any queries. Nevertheless an in-degree value of four is rather low. CM3 had several special training sessions on sustainable construction, such as in-house seminars on sustainable construction and environmental management of construction sites and should possess expert knowledge on the subject. However, as shown in Table 6.35, CM3 is not only giving, but also receiving a lot of knowledge on sustainable construction. When examining the kind of transferred knowledge in more detail, it strikes that he/she seems to be an expert on materials but a knowledge consumer on technologies.

CM4 is the architectural design manager, who had special training on sustainable construction in the form of a series of CPD courses. The advice he/she gives and also requests is on various combinations of all three subject areas. This could indicate him/her being a gatekeeper as well.

The centrality of Lift1, the supervisor of the lift company, is quite a surprise, as his/her job does not relate much to sustainability. Nevertheless Lift1 was aware of the sustainability goal of the project and had external training on sustainable construction, which he/she feels to require for his/her work life. Thus being knowledgeable seems to make him/her a knowledge source for the other actors.

It strikes that that CM6, the supervisor of the construction management company is clearly only a knowledge consumer with the second highest out-degree centrality. CM6 is requesting knowledge on materials only. Moreover he/she felt the requirement for special training but commented: '*I wasn't working there when the training was on'.*

CM1 is the intern in this case study, but seems to be rather a knowledge consumer than broker. CM1 stated that he/she did not have any training on sustainable construction yet and requests knowledge on all three subject areas.

As indicated in Table 6.35, the high centrality values of CM3, CM4 and Lift1 could indicate that these three actors are either gatekeepers or experts in one area and consumers in another. The following betweenness calculations will explore this issue further. Gatekeepers are important in this study as they pass on the knowledge on sustainable construction. The results are presented in Table 6.36.

Table 6.36: Betweenness Centrality Measures in Case Study UK2

Actor	Betweenness
CM2	373.5
CM3	362.75
CM4	176.75
Log1	173.25
Lift1	105

Table 6.36 shows that the main gatekeepers in this social network are:

- CM2, sustainability manager of this project
- CM3, construction project manager in charge
- CM4, professional of the construction management company
- Log1, supervisor of the logistics company
- Lift1, supervisor of the lift company

As stated previously CM2 is the sustainability manager and CM3 the project manager in charge. This explains the marked difference between the scores for these two actors and the others. All five actors had a high degree centrality value as well. However, as the previous investigation of transferred knowledge of these actors showed, only CM2, CM4 and Lift1 can be regarded as gatekeepers. CM3 seems to be an expert on materials and a knowledge consumer on technologies. In addition Log1 only discusses sustainable materials, probably due to his/her job role, i.e. dealing with the logistics of the construction project.

6.3.3.7. Knowledge Sources

This section explores the knowledge sources further, i.e. their role and what kind of relationship exists between the knowledge source and receiver, and why this person was chosen to ask for advice on sustainable construction. Thus more information on the tie characteristics is provided. Please see sections 3.4.1 and 5.3.1 for the discussion on knowledge repositories and sources. The results, analysed with content analysis, are summarised in Table 6.37. In total the participants provided this information for 47 knowledge transfers, thus the number in the right hand column is the count.

Table 6.37: Knowledge Sources and the Reasoning for this choice in Case Study UK2

Coding	Count
Colleague(on this project)	29
Colleague (on another sustainable project)	7
Colleague (from another company)	6
Environmental Manager	3
Supervisor	2
Total	**47**

As shown in Table 6.37 the most common knowledge source with 29 was a colleague on this project. Interestingly a colleague (29) is more frequently consulted over a manager (3) or a supervisor (2). Indicating the knowledge source also indicates to a certain extent the tie content trust, as by asking for advice the actor admits being less knowledgeable in the subject area (Borgatti, Cross, 2003). Trust does affect KT as argued in section 3.4.1.3. Hence it might not be a surprise that colleagues are chosen over managers and supervisors, as there might be more trust based relations amongst them, than with someone from a superior job level. Moreover colleagues working on the same project together might have developed a so-called ‘transactive memory’ (Wegner et al., 1991), i.e. they know ‘who knows what’ (Berends, 2005). Please see section 3.4.1.2 for more details on this subject. In addition the results on the choice of the knowledge source confirm the assertion from section 6.2.3.4 that the majority of the ties are relatively strong and thus facilitate the transfer of the large amount of tacit knowledge. This is in line with literature (Augier, Vendelø, 1999; Granovetter, 1973), i.e. tacit knowledge is best transferred through strong ties. Yet, the interesting aspect of this finding is that these strong ties exist in a sparse network, similar to the previous case study. Hence it shows that tacit knowledge can be transferred through a sparse network, if it consists of strong ties. These results are not in line with existing literature on network density, tie strength and tacit KT.

There is only a difference of one citation between colleagues from the same company working on another sustainable project, to colleagues from another company working at the same project. This suggests an equal importance of both. Moreover the social network structure presented in Figure 6.26 supports this finding. It shows the various participating companies, such as logistics, lifts or architects linked to each other through the construction management company.

Furthermore some research participants elaborated further on their choice to ask this specific person for advice on sustainable construction. 13 chose this person, simply because they were in charge. The others are divided into information (4), knowledge (4), advice (3) and experience (1). Although it can be assumed that practitioners in the field first ask the person in charge, it is surprising that trust was not mentioned at all in this case study.

In addition it was further examined, whether the previously identified perceived experts and consumers differ in their knowledge source choice. The following list shows who they prefer to ask.

Perceived experts:

- CM2 colleague
- Log1 colleague
- CM3 colleague
- CM4 colleague, consultant
- Lift1 colleague, client

Knowledge consumers or brokers:

- CM3 colleague
- CM6 colleague
- CM1 supervisor
- CM4 colleague, consultant
- Lift1 colleague, client

The findings on this issue concord with the main outcome, as colleagues are the preferred knowledge source also for knowledge consumers and perceived experts.

6.3.3.8. Relationships between Knowledge Transfer Methods and the Actor Attributes Age, Job Level and Actor Centrality

Regarding the KT methods especially for explicit knowledge in terms of achieving the sustainability goal of this case study some research participants mentioned a lack of understanding the BREEAM requirements for documentation and evidence. For instance one professional stated that '*requirements for documents and providing evidence, particular from whom it comes from, is less successful in this project. Clearer definition of requirements and consultant responsibility are needed. Briefing on changes in requirements and updates would be useful.*' The sustainability manager suggested '*more consistency in document collection. The BRE should have an online platform with one account per project, where you can submit and collect all documents during the assessment process. Every project participant has a password and can access the project account and see all documents and is up-to-date with the stage of assessment.*' This suggests that having a consistent up-to-date data base for the project could facilitate the overall KT on sustainability issues as well. As discussed in section 5.3.2 this relates to e.g. a pro-active approach to databases. Additionally this could contribute to the overall knowledge perception and awareness as presented in section 3.4.2.5. These are suggestions for the BRE that could offer a coherent knowledge vision and a better information sharing climate, as argued by Egbu (2004).

The methods used to seek the knowledge and those to receive it were investigated. The respondents filled in the methods used for each KT occurred and had the chance to add methods, if they used others. However, no research participant of this case study has added any method, while all offered methods have been used. This might suggest that all important methods were covered in the data collection tools. Figure 6.27 presents the findings.

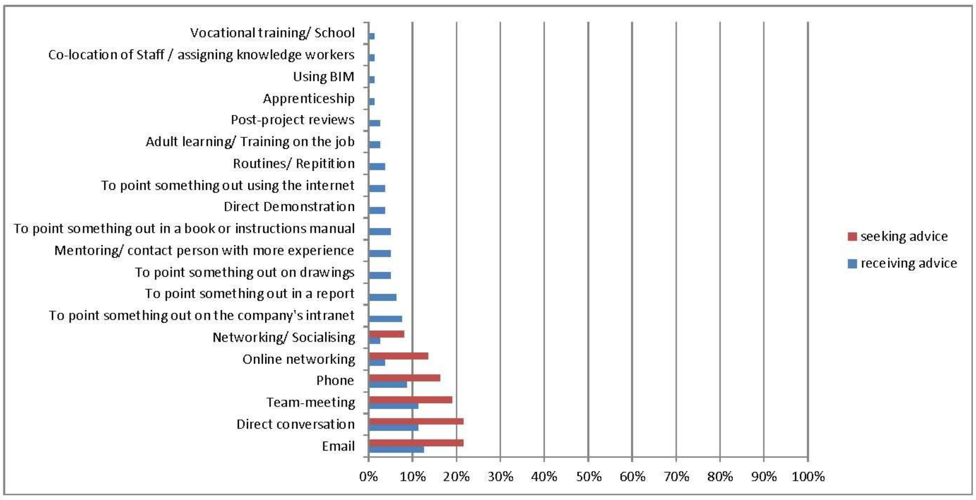


Figure 6.27: Knowledge Transfer Methods when seeking and receiving Knowledge in Case Study UK2

Figure 6.27 shows that the participants sought knowledge on sustainable construction by using email and direct conversation nearly at the same level. This is followed by team meetings, phone, online networking and socialising.

Most of the knowledge given was transferred using the same methods, i.e. email, direct conversation, team meeting and phone.

Therefore the ten most used methods to receive knowledge on sustainable construction in this case study were:

- Phone
- Email
- Team meeting
- Direct conversation
- Socialising
- Online networking
- To point something out on a drawing
- To point something out in the intranet

- To point something out in a report
- Mentoring

Most of these methods are according to literature (e.g. Haldin-Herrgard, 2000; Egbu, 2004) used to transfer tacit knowledge. As a result the choice of these KT methods gives further indications to the tie contents. As discussed in section 6.3.3.4, tacit knowledge was part of 58.82% of all knowledge transfers occurred. Thus this selection of KT methods provides further evidence of the transfer of a large amount of tacit knowledge through this rather sparse network. This argument is also supported by a statement of CM2, the sustainability manager. He/she is perceived by far as an expert on sustainable construction and recommends for enhancing the KT on sustainability issues in construction projects:

> *'The main cause of failure is a lack of understanding resulting from over complicated requirements and means of communication. To improve the 'transfer of knowledge' we should talk more and use email less. Anything we can do to simplify communication lines is essential. Having a simple clear message and communicating it well is always the best way to ensure success. Often technical content is far less important than actively meeting people and getting involved. Construction is a hands-on people business and distance can often be a problem. As all exercise has shown it's vitally important to KIS, i.e. keep information simple!'*

An interesting finding is that all methods were used to receive knowledge on sustainable construction. Nevertheless the two less used ones are vocational training and online networking. The fact that vocational training was used least, when receiving advice on sustainable construction could suggest a deficiency in education indicated by e.g. Dixon, Colantonio and Shiers (2008) and Steedman (2011), previously discussed in section 2.5.2.

The intranet is ranked as the 8th most used KT method which can be explained by the analysis of the qualitative data. One respondent stated '*I would imagine there is information about it in our intranet system, but I don't really know where nor have the time to read it*.' Another research participant supported this point of view by putting forward that *'there are no employees for KM in the company, or maybe a part-time one, trying to clean and organise the intranet.'* This point of view was supported by the sustainability manager, who explained '*I don't even know where to find what* [on the intranet]. *It's not used, so much information input, not well organised and not always up-to-date.'*

It is vital to investigate the interrelations between the various chosen KT methods and actor attributes, such as age, job level and centrality. Thus the following figures present the cross tabulation of these. As ten of the methods were previously identified as the most used ones the figures only focus on these.

Figure 6.28 presents the cross tabulation between age groups and the chosen KT methods.

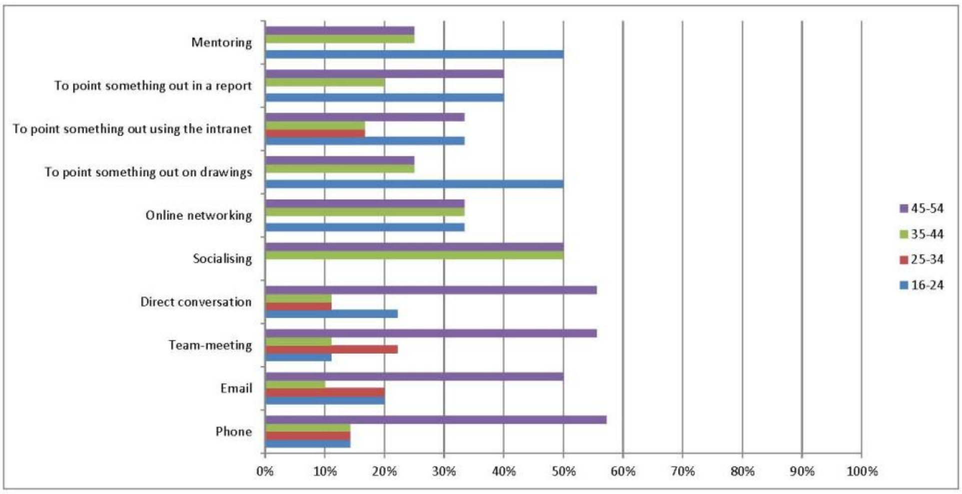


Figure 6.28: Knowledge Transfer Methods Cross Tabulation with Age Groups in Case Study UK2

As shown in Figure 6.28, there seems to be indeed a difference in the methods chosen to transfer knowledge on sustainable construction depending on the age group. The age groups 35-45 and 45-54 use all methods. Socialising is the only methods not used by the two youngest age groups (16-24, 25-34). Additionally the second youngest age group, i.e. 25-34 only used half of these methods. This might suggest that with increasing work experience, workers learn how to transfer knowledge on sustainable construction through a larger variety of methods. Thus these findings suggest a link between the actor attribute age, hence experience and KT methods. As presented in section 3.4.2.5, Riege (2005) states that the age differences of participants in a KT can enhance or inhibit it. The findings show that this could be due to for instance preferring to use different methods to transfer knowledge.

Figure 6.29 depicts the cross tabulation between job level and the chosen methods to transfer knowledge.

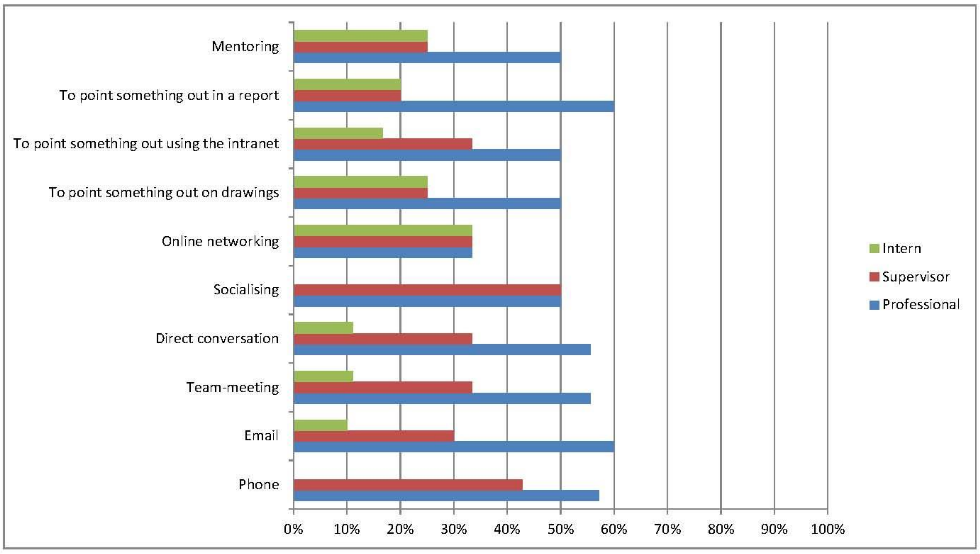


Figure 6.29: Knowledge Transfer Methods Cross Tabulation with Job Levels in Case Study UK2

As shown in Figure 6.29, there seems to be no difference in KT methods between the various construction workforce members according to their job level in this case study, apart from the intern not using phone or socialising. Hence there is no link between the choice of KT methods and the actor attribute 'job level'.

In the previous section 6.3.3.6 the following five actors were identified as perceived experts on sustainable construction with the highest in-degree centrality. It was considered vital to examine their choice of KT in more detail.

- CM2, professional → Phone, email, direct conversation, team meeting
- Log1, supervisor → Phone, email, direct conversation, team meeting, intranet
- CM3, professional → Email, direct conversation, team-meeting
- CM4, professional → Phone, email, direct conversation, team meeting, report, book
- Lift1, supervisor → Phone, email, direct conversation, team meeting, intranet

This shows that more central actors prefer similar KT methods as the other actors in this network. Moreover they mainly use the four most used methods as stated at the beginning of this section, i.e. phone, email, direct conversation, team-meeting. As a result it leads to the assumption that there is also no link between the choice of KT methods and actor centrality in this case study.

6.3.3.9. Duration of Knowledge Transfer

The conceptual framework was revised after the analyses of case study UK1, as the factor time, i.e. duration of the actual KT appeared to be more important than initially thought of. Therefore this factor was only included in the succeeding case studies. Table 6.38 depicts the results on this issue.

Table 6.38: Duration of Knowledge Transfers in Case Study UK2

Time in Minutes	Count	Percentage
2	3	5.88%
5	4	7.84%
10	22	43.17%
15	9	17.65%
20	3	5.88%
60	1	1.96%
No data	9	17.65%
Total	**51**	**100%**

The results for this case study show that most knowledge transfers (43.17%) take about 10 minutes, while most others are up to ten minutes or 15 minutes. Only one respondent indicated a single KT of 60 minutes. This aspect is vital as construction projects are usually under a certain time pressure. Previous studies stated that participants have argued with a general lack of time, respective the length of time that it would take to give advice (Hansen, 2002; Riege, 2005; Lu, Sexton, 2007). However, this result shows that it only takes on average about ten minutes to answer questions on sustainable construction. Hence this finding suggests that this rather small amount of time might be worthwhile to consider, if it leads to an overall better built result.

6.3.4. Conclusion

This section presented the data analysis of the second UK case study. It first provided a brief overview of the research settings and the general actor attributes of the research participants. Thereafter it was investigated to what extent the actor attributes and social network characteristics relate to each other and influenced the knowledge transfer on sustainable construction in this case study.

Table 6.39: General Factors and Social Network Characteristics influencing KT on sustainable Construction in Case Study UK2

	Awareness	Perceived Use of sustainable Material/ Technology	Training Received	Perceived Training Need	KT Methods	KT Source	Network Density	Job Level	Age
Age	x	x	√	x	√	NP	n/a	n/a	n/a
Gender	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Nationality	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Education	Linked to job level								
Job level	x	x	x	x	x	√	n/a	n/a	n/a
Tie Contents	n/a	n/a	n/a	n/a	√	NP	√	√	n/a
Actor Centrality	√	NP	√	√	x	√	n/a	√	x
Awareness	n/a	NP	n/a	n/a	n/a	√	n/a	x	x

√ - linked; x – not linked; NP – link not prominent enough; n/a – not applicable/ investigated

In summary the analysis carried out in this case study seems to suggest only a few links between some factors that influence KT on sustainable construction. However, the quality of the data was limited due to the small sample size (11) and the fact that only supervisors, professionals and one intern took part in this case study. As a result many of the detected links were not prominent enough in comparison to the first UK case study. Table 6.39 provides a summary of the findings, which will be explained in the succeeding paragraphs.

In relation to so-called general influencing factors (please see section 5.3.2 for more details), such as gender and nationality, no remarkable results have been detected due to the nature of the sample, i.e. participants were mostly male and British. However, as argued in section 3.4.1.1 the results on this issue might not fully reflect the cultural backgrounds of the respondents, as they were only asked for their nationality. Moreover the finding in section 6.3.2.2 confirmed that education defines job level later in life, hence these two actor attributes are linked. As a result succeeding analyses were conducted for job level only, though findings represent educational background as well.

The age group of the research participants did not influence the awareness, the perceived use of sustainable materials or the training needs. However a link between age group and received training was detected in section 6.3.2.5. All respondents, who have received a special training on sustainable construction, are of the age group 45-54. However, this could be due to the overall age range of the sample (i.e. 45.5% of the respondents were between 45-54 years old).

72.7% of the respondents in this case study were aware that the construction project strived to achieve a BREEAM certificate. Moreover 90.9% were aware that their companies use some kind of sustainable material or technology. Out of all respondents only 27.3% stated that they have had a special training on sustainable construction, while 54.5% acknowledged the requirement of such specific skills. As previously stated, due to the job levels of the sample, i.e. only professionals and supervisors, no links were found between these variables and job level. Nonetheless it was observed that, similar to the first UK case study there was a general lack of agreement whether special sustainability training is necessary or what it actually involves.

In regards to the social network characteristics, the network density was found to be relatively low with a value of 0.06. This shows a sparse network regarding the KT on sustainable construction in this project. Both tacit and explicit knowledge were transferred through this rather sparse network. In fact tacit knowledge was part of 58.82% of all KTs occurred. In addition, the link between tie contents and KT methods, asserted in the literature was confirmed, as the most frequently used KT methods indicate the transfer of tacit knowledge. Therefore this finding proves that it might be a sparse network but with rather strong ties. As discussed in section 4.4.1 and 4.4.2, Granovetter (1973) and Reagans and McEvily (2003) argue that the tie characteristics, i.e. strength or weakness, determine the type of knowledge that is transferred. Therefore these results confirm strong ties facilitating tacit KT in a sparse network. Hence this outcome is similar to case study UK1 and will also be observed in the German case studies.

Centrality measures showed which actors are perceived as experts on sustainable construction by others, and which rather consume knowledge. Here supervisors and professionals were both experts and knowledge consumers. This again is due to the overall job level structure of the sample. Nonetheless actors with a high in-degree centrality i.e. perceived experts showed more awareness of sustainable construction, received special training or felt the need for such training. Hence a link between centrality, awareness and training was detected. Moreover the findings suggest a relationship between tie contents and job levels, as knowledge on certain subject areas was required more frequently by certain job levels.

This construction project employed a sustainability manager. The high centrality values of the sustainability manager indicate a need for a sustainability manager or assessor in addition to the architect or construction project manager in order to have a contact person facilitating KT on sustainability throughout the project.

In regards to the relationship to the knowledge sources, colleagues (29) were by far more frequently consulted for advice on sustainable construction than managers (3) or supervisors (2), as there might be more trust based relations amongst them, than with someone from a superior job level. This finding is as expected and confirms the assumption that this is a sparse network, but with strong ties facilitating the transfer of tacit knowledge.

All KT methods of the conceptual framework were used. The only KT method added by one research participant 'workshops with specialist consultants' which could be allocated to adult learning. No link between the choice of KT methods and job level was found in this case study. Additionally the findings showed that the central actors do not use different or more methods than others. Yet there was a slight difference in the choice of KT methods detected depending on the age group. As argued in section 3.4.2.5, Riege (2005) states that the age differences of participants in a KT can influence its success. The findings show that this could be due to for instance preferring to use different methods to transfer knowledge.

This case study also collected data on the duration of the KTs. The findings show that most KTs only require 10 minutes, whilst most others are up to 10 minutes or 15 minutes. This suggests that this relatively small amount of time might be worthwhile if it improves the quality of the built outcome.

The next and final part of this chapter cross compares the analyses of the two UK case studies.

Key for Case Study UK2

indicates research participants

Trade	Code	Job Level	Code
Construction manager	CM	Intern	CM1
		Professional	CM2
		Professional	CM3
		Professional	CM4
		Professional	CM5
		Supervisor operatives	CM6
		Professional	CM7
		Professional	CM8
		n. a.	CM9
		n. a.	CM10
		n. a.	CM11
		n. a.	CM12
		n. a.	CM13
		n. a.	CM14
		n. a.	CM15
		n. a.	CM16
		n. a.	CM17
		Professional	CM18
		n. a.	CM19
		Professional	CM20
		n. a.	CM21
		n. a.	CM22
		Professional	CM23
On-site cranes etc.	Cra	Supervisor operatives	Cra1
Elevators/ Lifts	Lift	Supervisor operatives	Lift1
		Professional	Lift2
		Professional	Lift3
		Professional	Lift4
Site Logistics	Log	Supervisor operatives	Log1
		Professional	Log2
		Professional	Log3
		Professional	Log4
		Operative	Log5
		Operatives	Log6
Architects	Arc	Professional	Arc1
Services Consultants	Ser	Professional	Ser1
		Professional	Ser2
BREEAM Assessor	BREEAM	Professional	BREEAM1
Electrical Consultant	Elec	Professional	Elec1

6.4. Differences and Similarities of the UK Case Studies

This chapter presented the analyses of the two UK case studies. It has to be acknowledged that the sample size in case study UK2 is much smaller and it was not possible to collect data from operatives and apprentices. As a result the comparison of these two case studies is rather limited. Hence some conclusions derive only from case study UK1. Nevertheless certain trends emerged during analyses. These observations were taken into account and reflected on the conceptual framework using analytic generalization (Yin, 2014), as described in section 5.4. Figures 6.30 and 6.31 show sections of the original conceptual framework to ease the overview of the conclusions drawn from the UK case studies.

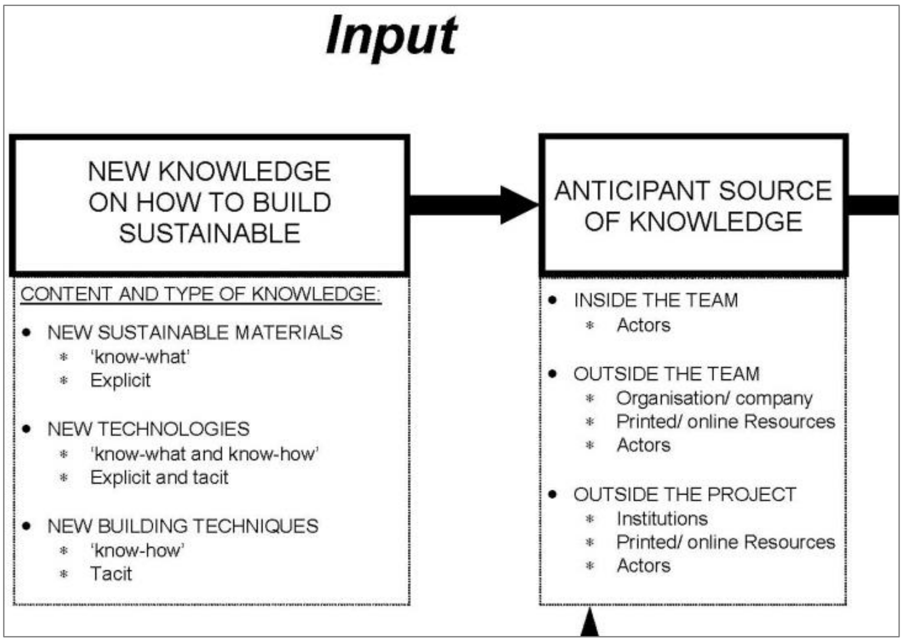


Figure 6.30: The Conceptual Framework – Input Section

The knowledge input section of the conceptual framework, illustrated in Figure 6.33, is devided into two parts, the new knowledge on sustainable construction and the anticipant source of this knowledge.

<u>New Knowledge on how to build sustainably</u>

Regarding the type and content of the new knowledge on sustainable construction, the three categories and their combination were accepted and used by all research participants. However, this could also be because the respondents did not have the interest, time or knowledge to make suggestions or amendments. Please see section 9.4 – Limitations.

The two most discussed subject areas in case study UK1 were materials and a combination of all three subject areas, i.e. materials, technologies and techniques. In case study UK2 the respondents indicated that a combination of all three subject areas was by far the most required knowledge. In addition both case studies showed that it largely depends on the job level of the actor which subject area is discussed more. However, this link was found to be more prominent in case study UK1. Furthermore the research findings of UK1 show that more subject areas were covered by professionals, while operatives were rather discussing only one of the categories. Both findings imply a link between job level and tie contents.

Moreover the above mentioned observations appear to confirm the categories in which the new knowledge on sustainable construction was divided. The best aspect of these categories seems to be the variety of possible combinations of the three subject areas in order to designate exactly the knowledge transferred, as all respondents made good use of it.

<u>Anticipant Source of Knowledge</u>

The knowledge sources were identified by actor centrality measures, both degree and betweenness centrality. The results showed who is perceived by the others as an expert on sustainable construction, who acts as a gatekeeper and actively enhances the KT, and who is just a knowledge consumer.

In case study UK1 supervisors and professionals were perceived as experts, whereas operatives were mostly knowledge consumers. As a result there seems to be a link between actor centrality and job level, as expected. As already argued in Chapter 2, specialist knowledge and thus specialists are required to deliver sustainable office buildings. The findings suggest that this is becoming the case, as supervisors of sub-contractors are regarded as experts. Furthermore the high centrality values of the sustainability manager in case study UK2 might suggest employing a sustainability manager in order to provide a contact person for sustainability issues and to enhance the KT in the construction project.

Additionally in regards to the relationship towards the knowledge sources, in case study UK1 colleagues were more frequently consulted as knowledge sources on sustainable construction than managers and supervisors. This is followed by colleagues from other companies involved in the same project. In case study UK2 colleagues were by far the most preferred knowledge source as well. Here it was argued that indicating the knowledge source also indicates to a certain extent the tie content trust, as by asking for advice the actor admits being less knowledgeable in the subject area (Borgatti, Cross, 2003). Trust does affect KT as argued in section 3.4.1.3. Hence it might not be a surprise that colleagues are chosen over managers and supervisors, as there might be more trust based relations amongst them, than with someone from a superior job level. Moreover colleagues working on the same project together might have developed a so-called ‘transactive memory’ (Wegner et al., 1991), i.e. they know ‘who knows what’ (Berends, 2005). Please see section 3.4.1.2 for more details on this subject. In addition the results on the choice of the knowledge source confirm the assertion that the majority of the ties are relatively strong and thus facilitate the transfer of the large amount of tacit knowledge in both case studies. This is in line with literature (Augier, Vendelø, 1999; Granovetter, 1973), i.e. tacit knowledge is best transferred through strong ties.

It was assumed that due to the silo-based structure of the industry in which projects are organised along disparate disciplinary boundaries (e.g. WBCSD, 2008) there would be no significant link between various participating companies. Yet the network structure of both case studies showed a relatively good cooperation between the involved trades, though mainly through the construction management company. This finding was more prominent in UK1. Nonetheless this observation could only be the case during construction phase and in the context of KT on sustainable construction.

In summary the knowledge sources on sustainable construction used in these two case studies are to be found mainly inside the immediate work team, i.e. colleagues and supervisors. In case study UK1 actors outside the immediate work team but inside the same construction project, i.e. colleagues from other involved companies, were used as a main knowledge source as well. Nonetheless the respondents mainly named actors as knowledge sources. As a result printed and online resources, shown as knowledge sources in the original framework might be better allocated in the KT process, methods/ mechanisms section of the conceptual framework, which will be discussed next. It will be observed in the German case studies if this trend continues and thus justifies a change of the framework.

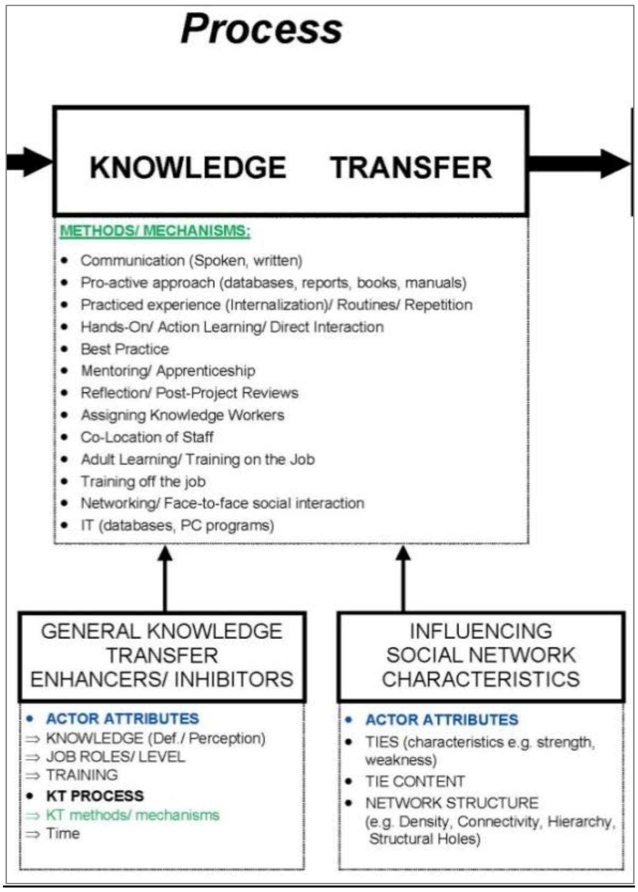


Figure 6.31: The Conceptual Framework – Process Section

KT Process/ Methods and Mechanisms

Figure 6.31 illustrates the KT Process section of the original conceptual framework. In section 3.4.2.3 several meachanisms drawn from literature were assumed to be appropriate for the KT on how to build sustainably. Thereafter methods were assigned to those mechanisms, as presented in Table 6.40. The respondents indicated which of these KT methods they used to transfer sustainable construction knowledge.

Table 6.40: Knowledge Transfer Process/ Methods and Mechanisms

Mechanisms	Methods
Communication (Spoken, written)	Direct conversation Phone E-mail Team-Meeting
Pro-active approach (reports, books, manuals)	To point something out in a report To point something out in a book or instructions manual
Practiced experience (Internalization)/ Routines/ Repetition	Routines/ Repetition
Hands-On/ Action Learning/ Direct Interaction	Direct Demonstration To point something out on drawings
Best Practice/ Reflection	Post-Project Reviews
Mentoring/ Apprenticeship	Mentoring/ contact person with more work experience Apprenticeship Vocational Training/ School
Assigning Knowledge Workers	Assigning Knowledge Workers
Co-Location of Staff	Co-Location of Staff
Adult Learning/ Training on-the-job	Adult Learning/ Training on-the-job
Training off-the-job	Adult Learning
Networking/ Face-to-face social interaction	Networking/ Socialising Online networking
IT (databases, PC programs)	To point something out using the internet To point something out on the company's intranet Using BIM

First all methods were used in both case studies, but the methods differed with regards to seeking or receiving the requested knowledge. The findings of the two UK case studies showed that the following methods were used most in order to receive knowledge on how to build sustainably. The order is according to the frequency.

UK1

- Phone
- Direct conversation
- Email
- Team meeting
- Direct demonstration
- To point something out on a drawing
- To point something out in the internet
- To point something out in a report
- Mentoring

UK2

- Phone
- Email
- Team meeting
- Direct conversation
- Socialising
- Online networking
- To point something out on a drawing
- To point something out in the intranet
- To point something out in a report
- Mentoring

As a result it is clear that nearly the same methods were preferred in both case studies. A slight difference is only that the second case study also used socialising and online networking. Moreover the respondents of UK2 preferred the intranet towards the internet. This finding from the questionnaire data is in contrast to statements provided by three respondents on the disadvantages of the intranet. The only KT method added by one research participants in case study UK2 was ‘workshops with specialist consultants’. It can be assumed that this is included in ‘adult learning’.

In both case studies the methods chosen to transfer knowledge on sustainable construction differed depending on the age of the actors. In UK1 for instance the oldest age group (55-65) preferred using drawings, direct conversation, team meetings and phone, than more IT related methods. In UK2, the age groups 35-45 and 45-54 use all methods. Socialising is the only method not used by the two youngest age groups (16-24, 25-34). Additionally the second youngest age group, i.e. 25-34 only used half of these methods. As presented in section 3.4.2.5, Riege (2005) states that the age differences of participants in a KT can enhance or inhibit it. The findings show that this could be due to for instance preferring to use different methods to transfer knowledge.

Furthermore there is a clear link between the choice of KT methods and job level in case study UK1. The supervisors seem to use nearly all methods, while the construction workforce and professionals used different ones, i.e. professionals preferred more IT related KT methods and operatives more direct ones. This might be due to the supervisors acting as an interface between professionals and operatives. Section 3.4.2.5 presented that the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which could also inhibit KT. These findings suggest arranging the KT methods in the conceptual framework by job level, if this phenomenon reappears in the other case studies. Nonetheless this phenomenon could not be observed in case study UK2, as no data from operatives was collected.

In summary the results show that the KT process was influenced by general actor attributes, as part of the general KT enhancers and inhibitors, such as job level and age of the involved actors. Regarding the social network characteristics actor centrality did not affect the choice of KT methods, while there was a link between tie contents and chosen methods detected. Most of the chosen methods are according to literature (e.g. Haldin-Herrgard, 2000; Egbu, 2004) used to transfer tacit knowledge. As a result the choice of these KT methods gives further indications to the tie contents. Thus this selection of KT methods provides further evidence of the transfer of a large amount of tacit knowledge through the rather sparse networks in both case studies.

<u>General Knowledge Transfer Enhancers/ Inhibitors</u>

In relation to so-called general influencing factors ‘actor attributes’, such as gender and nationality, no remarkable results have been detected due to the nature of the samples, i.e. participants were mostly male and British. Although some respondents might have a multi-cultural background, this is not fully captured in the results, as stated in section 3.4.1.1. Moreover the findings of both case studies confirmed that education defines job level later in life, hence these two actor attributes are linked. As a result succeeding analyses were conducted for job level only, while its results stand for educational background as well. Nonetheless educational background was not part of the original conceptual framework.

The variable ‘definition and perception of knowledge’ was tested by asking questions on the awareness of sustainability and the use of sustainble materials/ technologies. In both case studies more respondents were aware of their company’s use of sustainable materials and technologies, than of the overall sustainability aim of the project. Moreover sustainable materials and technologies named and used by the respondents were in fact sustainable. This suggests that amongst those who elaborated on this matter, there is a very high level of understanding and awareness about sustainable materials and technologies. However, since the research participants seemed to not necessarily link the use of sustainable materials/technologies to the project aiming for a sustainability certificate, this suggests to better inform all project participants of the sustainbility aim of the project.

In addition there are a few remarkable findings when looking at case study UK1 only, due to the respondents' job levels. For instance the differences in awareness towards sustainable construction varied depending on the job level, i.e. unawareness of sustainability was only found within the construction workforce. In addition the training needs differed depending on the job level as well, i.e. 87.5%, who received a training were operatives or supervisor.

In both case studies more people felt the need for training on sustainable construction than actually received it. However, there was an overall lack of agreement whether such training is actually necessary. Moreover, when naming sustainable training, respondents of both case studies did name all received training, without differentiating whether it was actually on sustainable construction. This finding suggest more training on sustainable construction should be offered to meet this need, and to raise the overall awareness of sustainability throughout the workforce.

An interesting coincidence was that both case studies did have interns, i.e. Bachelor students on their placement working for the construction management company. The intern in case stuy UK1 seemed to enhance the KT between some of the companies. This might be due to his/her rather low job level, which made him/her more approachable, combined with an affiliation to the construction management company. This suggests employing an intern due to the possible enhancement of KT throughout the construction project. Nonetheless, the intern in case study UK2 was just a knowledge consumer. Both interns indicated to have not received any special training on sustainable construction beforehand. As a result this might suggest employing an intern with the construction management company to enhance the KT, but only if he/she is knowledgeable enough.

Data on the factor 'time', i.e. duration of the KTs was collected in the second case study. The findings show that most KTs only require 10 minutes, whilst most others are up to 10 minutes or 15 minutes. This suggests that this relatively small amount of time might be worthwhile if it improves the quality of the built outcome.

In summary the findings show that most general knowledge transfer enhancer/ inhibitors affected each other and the KT process. Although it was not possible to detect this for personal actor attributes, such as gender and nationality due to the nature of the samples, it was proven that age, awareness, educational background/ job level and training were linked to each other and defined the KT methods chosen, the knowledge subject area requested, the network position and the choice of knowledge sources.

Influencing Social Network Characteristics

Some of the influencing social network characteristics were already discussed in the previous paragraphs as they influenced the actor attributes or the methods. For instance, a link between tie contents and job level was identified. Moreover actor centrality was used to determine the knowledge sources. Yet there was no link observed between actor centrality and the choice of KT methods.

The discussed subject areas give further indications on the knowledge type transferred and thus can be linked back to the tie characteristics and the network structure. Therefore the relatively large amount of transferred tacit knowledge through the sparse networks of both case studies is a remarkable finding and could indicate strong ties. As Augier and Vendelø (1999) put forward that tacit knowledge is best transferred through strong ties. This is also supported by Granovetter (1973) and Fernie *et al.* (2003), as discussed in section 4.4.2. Strong ties can be defined by long, close relationships with high trust (Granovetter, 1973). Therefore the results on the choice of the knowledge sources confirmed the assertion that the majority of ties are relatively strong and facilitate this KT. Nevertheless, the results of both UK case studies show that these strong ties exist in a sparse network. This is a significant finding, as it questions existing literature through showing that tacit knowledge can be transferred through a sparse network, if it consists of strong ties. Therefore this indicates a need for more research on the matter of network density, tie strength and tacit KT.

Concluding in terms of whether social network characteristics affected the KT, it was observed in both UK case studies that the strength of ties, the tie content and the network structure did indeed have an effect on KT on sustainable construction. Furthermore a link between tie contents and KT methods was detected, as the most frequently used KT methods proved the transfer of a large amount of tacit knowledge in both case studies. Additionally the findings showed that most central actors do not use different or more methods than others.

The next chapter will present the findings of the three German case studies.

CHAPTER 7

GERMAN CASE STUDIES

7.1. Introduction

This chapter presents the findings of the three German case studies using a structure similar to Chapter 6. Hence each of the three main sections begins with briefly outlining the research setting of each case study. Thereafter the findings of the descriptive statistics on the so-called actor attributes and their possible relationships are debated. This is followed by presenting the SNA. Here the results on network structure, density, tie contents, actor centrality and their possible links with each other, and with the actor attributes and chosen KT methods are examined, in order to determine the extent to which they influenced KT on sustainable construction.

7.2. Case Study Germany 1 - Southwest

7.2.1. Research Setting

The construction project was located in a large city in the South-West of Germany. It was a built to suit prime office development of approximately 2,400 square meters. The project was completed in November 2011 and achieved a DGNB Gold certificate in 2012.

The project attained the following scores in the six main criteria groups of the DGNB certificate presented in section 2.4.3.

Table 7.1: Sustainable Performance of Project Germany1

Categories	**Score**
Overall quality of the building	82.2%
Ecological Quality	89.2%
Economic Quality	90.6%
Sociocultural and functional quality	73.7%
Technical quality	77.5%
Quality of the process	77.0%
Quality of location	67.7%

The fieldwork was carried out in February 2012. Thus the construction project was already completed and a data collection on-site was not possible. As a result a meeting with the DGNB auditor, who was also the building physician was arranged, who filled in the questionnaire. This was followed by an interview on the DGNB sustainability certificate in general, and the course of this construction project and its knowledge transfer in particular. The succeeding questionnaires were collected through emails only. Unfortunately this resulted in a low participation by only professionals and supervisors. A total of six questionnaires were collected, in addition to one interview.

7.2.2. Actor Attributes

This section presents the univariate analyses of the so-called actor attributes followed by a bivariate analysis to explore any relationships between these attributes.

7.2.2.1. Age, Gender and Nationality

Figure 7.1 shows that the age range of the research participants in this case study was diverse, with 16.7% between 25 and 34, and 35 and 44. 66.7% of the participants were between 45 and 54. There were no participants from the age groups 16-24 and 55-64. As illustrated in Figure 7.2 all respondents were male (100%). In addition, all respondents were German (100%) (see Figure 7.3). Since most participants were German and male, no remarkable results could be found in cross tabulation with these variables. The multi-cultural background of the respondents was not taken fully into account by the term nationality, as the participants expressed their citizenship only. As a result ‘age group’ was singled out of these three variables for succeeding analyses.

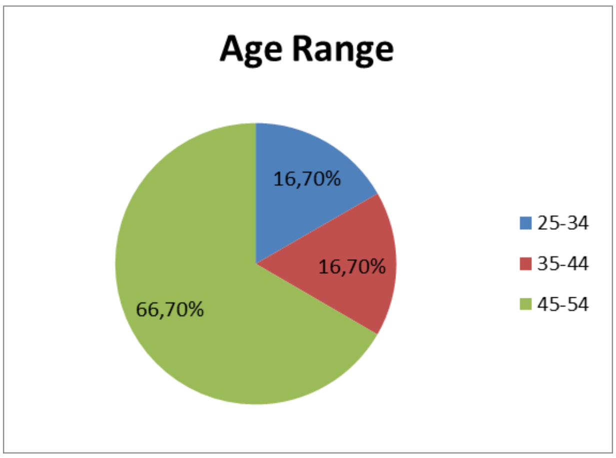


Figure 7.1: Age Range of Research Participants in Case Study Germany1

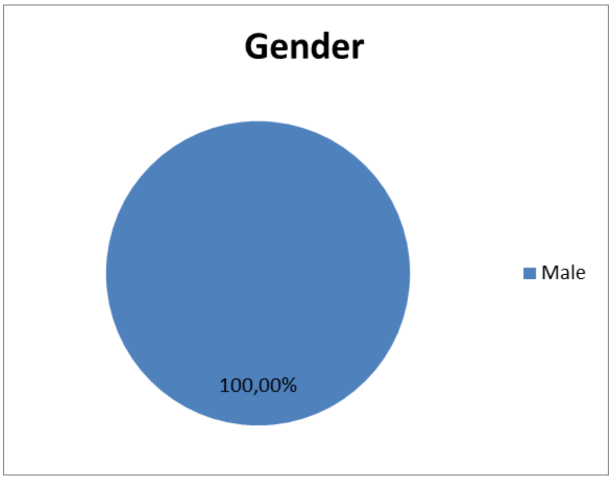


Figure 7.2: Gender of Research Participants in Case Study Germany1

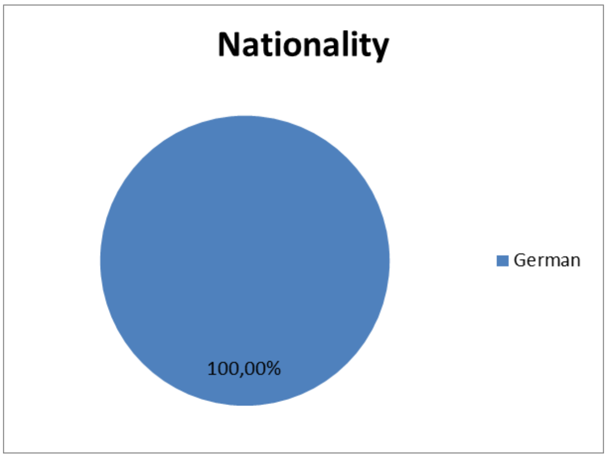


Figure 7.3: Nationality of Research Participants in Case study Germany1

7.2.2.2. Educational Background and Job Levels

Figure 7.4 illustrates the educational background of the research participants. 66.66% hold a German Diplom, which is equivalent to a Master's degree, while 44.44% completed a vocational training. This result is due to the German educational system, as Bachelor and Master degrees were only introduced after the Bologna Process in 1999, with the aim of having changed the German degree system from Diplom to Bachelor and Master degrees by 2010 (Schmidt, 2013). Therefore depending on the age of the project participant, he/she rather holds a Diplom.

As presented in Figure 7.5 this case study included only professionals (66.7%) and supervisors (33.3%). As previously stated, this was due to the unfortunate timing of data collection after project completion.

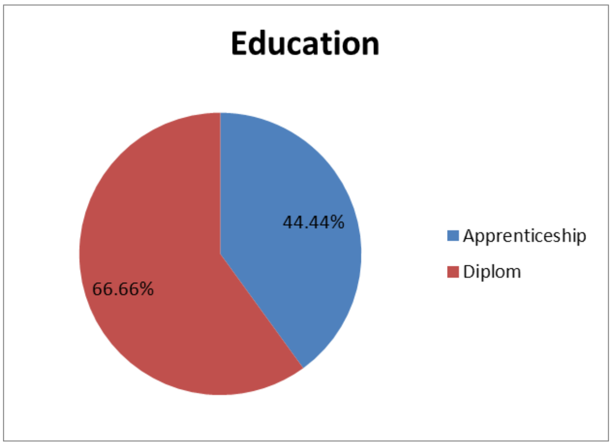


Figure 7.4: Educational Background of Research Participants in Case Study Germany1

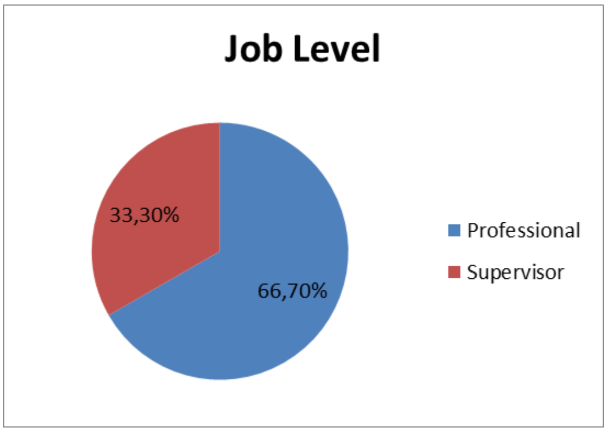


Figure 7.5: Job Level of Research Participants in Case Study Germany1

Table 7.2 confirms the strong relationship between 'educational background' and 'job level', as expected. As a result the succeeding analyses in this case study will equate 'educational background' with 'job level'. Hence bivariate analyses conducted for 'job level' only stand for both variables.

Table 7.2: Cross Tabulation between educational Background and Job Level in Case Study Germany1

	Job Level		**Total**
Educational Background	Professional	Supervisor	
Apprenticeship	0	2	2
Diplom	4	0	4
Total	4	2	6

7.2.2.3. Awareness of Sustainability

Figure 7.6 shows that 100% of the respondents in this case study were aware that this construction project strived to achieve a DGNB certificate. This is an exceptionally high result and was only reached in this case study. Nevertheless, this might be due to the small sample size, i.e. six participants, and sample nature, i.e. only professionals and supervisors. One respondent elaborated on this by stating: '*I was made aware of it through tendering documents and the contract*.' This could imply that for instance an operative might not read the tendering documents or sign the contract and hence might be less aware. However, it was not possible to explore this issue further. Nevertheless since all respondents were aware, it was also not possible to further investigate, if 'awareness of sustainability' is linked to 'age group' or 'job level'. As a result there are no links between these variables in this case study.

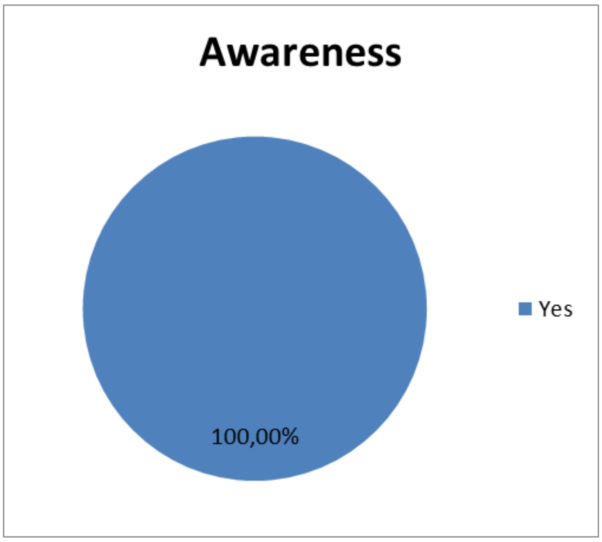


Figure 7.6: Awareness of Sustainability of Research Participants in Case Study Germany1

7.2.2.4. Perceived Use of Sustainable Materials and Technologies

As illustrated in Figure 7.7 only 33.3% of the respondents indicated that their companies actually use sustainable materials or technologies.

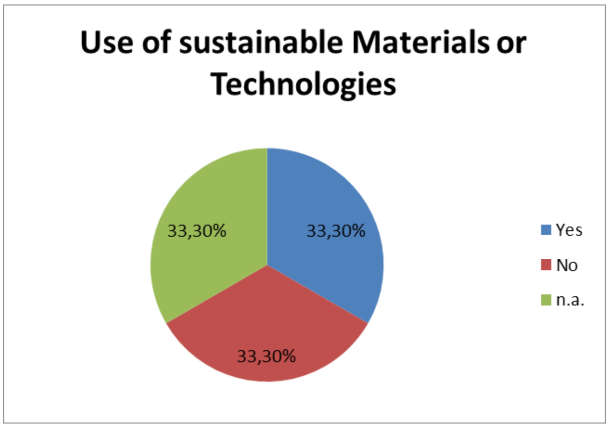


Figure 7.7: Perceived Use of sustainable Materials/ Technologies of Research Participants in Case Study Germany1

The following cross tabulation does not confirm a relationship between the 'perceived use of sustainable materials/ technologies' and 'job level', as the answers are widely spread between the two job levels. Nonetheless two professionals did not reply to this question. As stated previously professionals often misinterpreted this question as to the actual use, i.e. installation of a sustainable material/ technology. Surely the professionals, e.g. architects are involved in the specification process of which sustainable materials and technologies are to be used in this project.

Table 7.3: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Job Level in Case Study Germany1

	Perceived use of sustainable materials and technologies			**Total**
Job Level	**Yes**	**No**	**Not ticked**	
Professional	1	1	2	4
Supervisor	1	1	0	2
Total	2	2	2	6

The following cross tabulation shows that there is no link between the 'perceived use of sustainable materials/ technologies' and 'age groups' in this case study.

Table 7.4: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Age Groups in Case Study Germany1

	Perceived use of sustainable materials and technologies			**Total**
Age Group	**Yes**	**No**	**Not ticked**	
25-34	1	0	0	1
35-44	0	1	0	1
45-54	1	1	2	4
Total	2	2	2	6

The respondents elaborated further on the use of sustainable materials and technologies, which was analysed using content analysis, as described in section 5.6.3. This data derives only from the respondents, who elaborated further on this topic. The responses are summarised in Table 7.5. The two materials and technologies named by research participants can be regarded as sustainable and support the result of an overall high awareness towards sustainability in this construction project.

Table 7.5: Perceived Use of sustainable Materials/ Technologies of Research Participants in Case Study Germany1

Code	**Count**	**Percentage**
No actual usage because professionals	2	33.33%
Our consultancy strives to consider sustainability aspects	1	16.66%
Our company prefers to buy sustainable materials	1	16.66%
Variety of loam rendering	1	16.66%
Waste control / garbage recycling	1	16.66%

7.2.2.5. Received and Required Training on Sustainable Construction

Figure 7.8 illustrates the received training on sustainable construction, while Figure 7.9 presents the perceived requirement of such training.

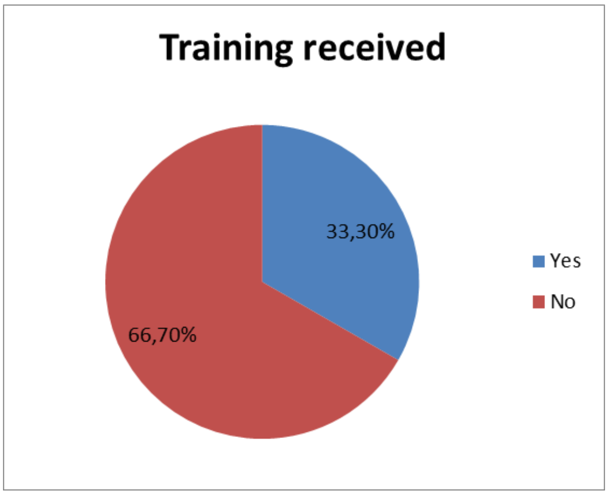


Figure 7.8: Training on sustainable Construction received by Research Participants in Case Study Germany1

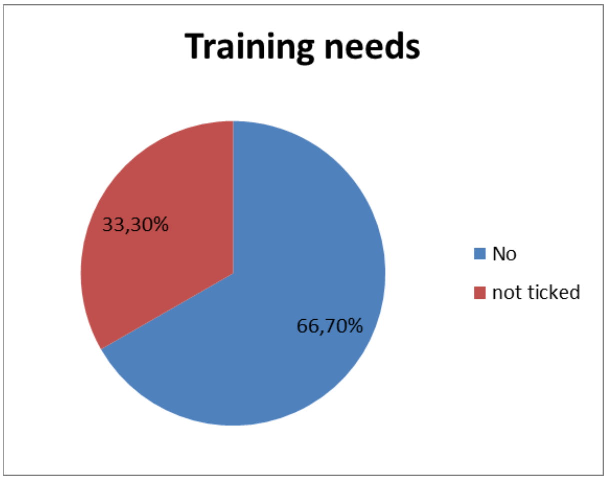


Figure 7.9: Perceived Requirement for Training on sustainable Construction by Research Participants in Case Study Germany1

Figure 7.8 shows that 33.3% of the participants had special training on sustainable construction, while 66.7% stated that they did not receive such training. The same number stated that they see no requirement for special sustainability training. One respondent elaborated on this by stating: '*No, our company uses sustainable materials, but they require no specific training on how to put them together.*' This point of view was generally very often observed while carrying out data collection in all case studies in both countries. There are of course several sustainable materials, such as sustainably sourced timber or hemp insulation, which simply replaced less sustainable ones and are built in in the same way. Nevertheless, as argued in section 5.3.1 there are also more sophisticated new sustainable materials and technologies, such as rain water harvesting that do require new techniques for their installation. Apparently the research participants in this case study worked with simpler materials.

Although the sample in this case study is very small, it was examined whether there is a link between training on sustainable construction and the actor attributes ‘age group’ and ‘job level’. The results of these cross tabulations are summarised in Tables 7.6 to 7.9.

Table 7.6: Cross Tabulations between received Training and Age Group in Case Study Germany1

	Received training		**Total**
Age Group	Yes	No	
25-34	0	1	1
35-44	0	1	1
45-54	2	2	4
Total	2	4	6

Table 7.7: Cross Tabulation between Training Needs and Age Group in Case Study Germany1

	Perceived training needs	**Total**
Age Group	**No**	
25-34	1	1
35-44	1	1
45-54	2	2
Total	4	4

Interestingly the respondents, who stated to have had additional training towards sustainable construction, were all part of the age group 45-54. This might suggest that with more work experience, the practitioners acknowledge their need for further training more and are willing to participate in one. However, the other four research participants stated that they do not require such training, and are of all three age groups, i.e. also 45-54. Hence this outcome is most likely due to the age range of the sample. Hence the link between ‘training’ and ‘age group’ is not very prominent in this case study.

Table 7.8: Cross Tabulation between Job Level and received Training in Case Study Germany1

	Received training		Total
Job Level	Yes	No	
Professional	2	2	4
Supervisor	0	2	2
Total	2	4	6

Table 7.9: Cross Tabulation between Job Level and Training Needs in Case Study Germany1

	Perceived training needs	Total
Job Level	No	
Professional	3	3
Supervisor	1	1
Total	4	4

Table 7.8 shows that the two respondents who received special training on sustainable construction were both professionals. Both supervisors did not receive such training. As four professionals and two supervisors participated in this study it is interesting to see in Table 7.9 that three professionals stated they do not feel they require such training. Thus at least one who received training found it not necessary after all.

The perception of what exactly training on sustainable construction is varied extremely throughout this research project. The participants of this case study mentioned more sensible opinions on this issue compared to other case studies. This is again most probably due to the nature of the sample, as only professionals and supervisors. The results are presented in Table 7.10.

Table 7.10: Perceptions of sustainable Construction Training in Case Study Germany1

Code	Count	Percentage
First sustainable construction project	2	40%
Training through DGNB	2	40%
Learning by doing	1	20%

Since only two participants indicated to have undergone training on sustainable construction one can see in Table 7.10 that those two have received their training from the DGNB organisation. Moreover, as the other four respondents indicated to have not yet undergone training, the comments show that for two of them this is because it was the first sustainable construction project so far. This could mean either that specific training was not yet needed or it is expected by their employer that they rather learn on-the-job. For one research participant '*learning by doing'* is so far sufficient.

'Learning by doing' was one of the KT methods in the conceptual framework presented in section 5.3. Hence in terms of testing the conceptual framework in practice, this statement was taken into account and observed for the other case studies.

During the interview Phy1/Aud1, i.e. the DGNB auditor/building physician admitted to feel *'lacking management and organisational skills to deal with all these enquiries and did not feel trained enough for these tasks or responsible for answering everything.'* He suggested creating a new job role with specialised training to handle these issues. This could be a sustainability manager as or instance in the UK2 case study. As previously stated, Thomson *et al.* (2010) suggested employing a sustainability expert to ease the KT during the project.

The next section examines the social network characteristics, their relationships and to what extent they influenced KT on sustainable construction.

7.2.3. Social Network Characteristics

The knowledge transfer network of this case study is depicted in Figure 7.10. The colour coding and line weights are presented in line with the description provided in section 5.6.4. Please also see the key at the end of the case study for an easier understanding of figures as the chapter progresses.

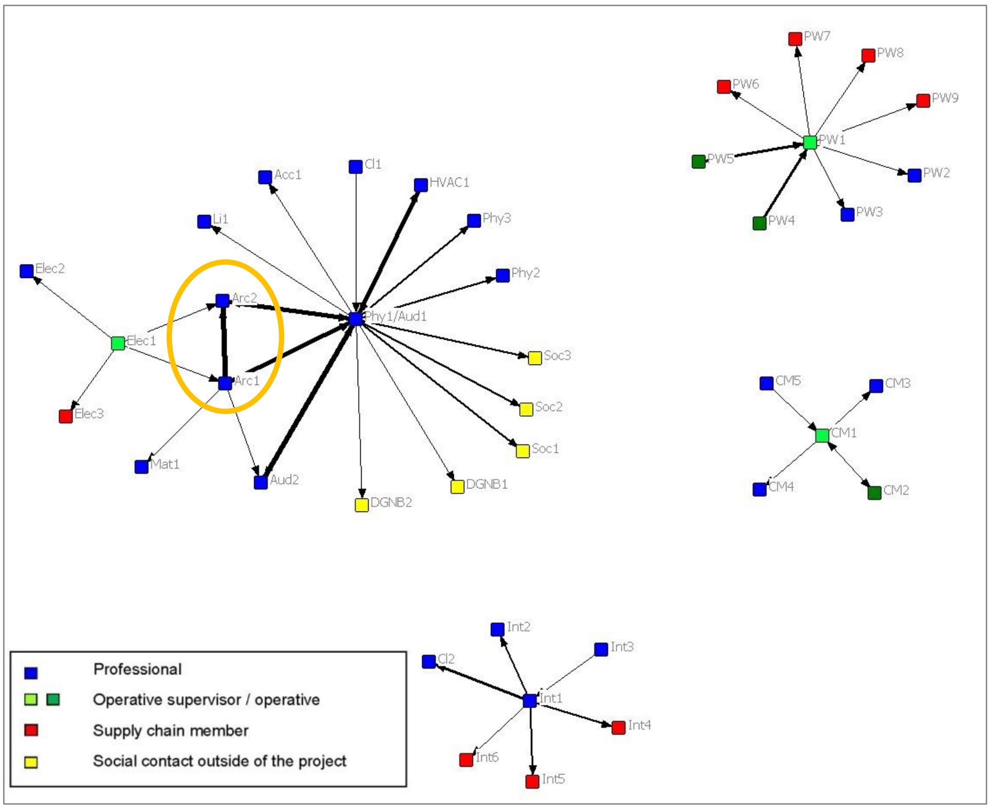


Figure 7.10: Knowledge Transfer Network of Case Study Germany1

7.2.3.1. Size of the Network

This network comprises of 38 nodes. The fold-out key at the end of this case study shows that only six out of the 38 actors were research participants. The other 32 actors were named by them. Nevertheless, all of the 38 were involved in the same construction project or participating companies, except for the five social contacts. As stated in section 5.5.2.1 the network boundary was defined as all participants on one particular sustainable office construction project. The sampling, which led to these six research participants is presented in section 5.4.2.

7.2.3.2. Network Structure

The network structure consists of four components: one main component and three slightly smaller components. The main component includes the following companies: architects, electrical contractors, building physics, sustainability assessors, material check-up, HVAC and plumbing, client/ landlord, lighting and acoustics.

Each of the smaller components represents one company, i.e. interior fittings, construction management and plaster works. This network structure partially derives from the respondents' behaviour, i.e. the more central actors Arc1, CM1, Elec1, PW1, Phy1 and Int1 were research participants. Nevertheless, this structure also indicates that the actors of these three smaller components rather share knowledge within their company and with their supply companies, than with others on the project. This behaviour might be caused simply by competition, as argued by Sharkie (2003). When examining the issue in more depth it becomes clear that the interior fittings and plaster work company ask their suppliers for advice on sustainable materials only, as assumed. However, an interesting aspect of this is that these three companies also seem to not require any knowledge on sustainable construction from any of the main component's actors. Moreover one of the companies is the construction management company which is a rather odd outcome, as these usually take a very central role in a construction project. This network structure results most likely from the fact that it was not possible to administer the questionnaire on-site as in the other case studies. Moreover respondent behaviour is further reason for this network structure, particularly for supervisors being in such central positions within the smaller components. As shown in the fold-out key at the end of this case study CM1, PW1 and Int1 were research participants.

7.2.3.3. Cut-points and Hierarchy Levels

When discussing cut-points in this social network, the focus is on the main component of the network, since the three smaller components each only possess one obvious cut-point in their centre, i.e. PW1, CM1, Int1. Please see section 4.4 for a definition on cut-points.

Arc1 and Arc2, indicated in Figure 7.10 with an orange circle, are the other cut-points, connected to the electricians (Elec1) and Mat1. This outcome is most likely due to the nature of their jobs as architects. When examining which knowledge was transferred in detail, it is clear that Arc1 and Arc2 discuss all three subject areas combined. However, all other KTs, i.e. Arc1 with Phy1, Aud2, Mat1, Elec1 only evolve around sustainable materials.

It is very difficult to make a statement regarding the hierarchy levels in this social network, as it is relatively small and distributed into four components. In addition to this, it was not possible to include operatives and apprentices as research participants. Therefore the only three operatives in this network are PW4, PW5 and CM2 and were named by PW1 and CM1. Yet, regarding the plasterworks component, PW1, a supervisor, requests knowledge from professionals and supply chain members and passes it on to the operatives. Thus this KT is rather along the hierarchy lines as expected. In the other smaller components, i.e. the construction management company and the interior fittings one, the KT is more mutual and not only top-down. The KT in the main component is dominated by Aud1/Phy1, who also includes social contacts from outside the project to receive advice on sustainable construction. In summary it seems as if the hierarchy is not influencing the KT direction in this case study.

7.2.3.4. Relationship between Network Density and Tie Characteristics and Tie Contents

The network density is 0.0532 with a standard deviation of 0.3811. This value indicates a mean strength of all possible ties of 0.05, i.e. 5% of all possible ties are present in this network (Hanneman and Riddle, 2005). As discussed in Chapter 4 the maximum value would be 1.0, i.e. 100% of all possible ties being present. 0.05 is a very low value, implying that this network is rather sparse than cohesive. The standard deviation is larger than the mean, which indicates no variation in the strength of ties, i.e. frequency of KT.

As previously argued there is a link between the strength of a tie and the type of knowledge that is transferred through it. Weak ties seem to limit the exchange of tacit knowledge (e.g. Reagans, McEvily, 2003; Granovetter, 1973; Fernie *et al.*, 2003). As a result it is vital to further examine the content and type of transferred knowledge, in order to make a statement on this matter for this case study. Moreover the results could indicate what kind of knowledge is required more and by which workforce group. Table 7.11 provides an overview of the frequencies of the various tie contents of the 41 KTs the research participants provided data.

Table 7.11: Tie Contents of Knowledge Transfers in Case Study Germany1

Tie Content	**Knowledge Type**	**Frequency Count**	**Valid Percentage**
Materials	Explicit	16	39.02%
All: Materials, Technologies and Techniques	Explicit and tacit	7	17.07%
Techniques and Technologies	Explicit and tacit	6	14.63%
Techniques	Tacit	3	7.31%
Materials and Technologies	Explicit and tacit	2	4.87%
Technologies	Explicit and tacit	2	4.87%
Materials and Techniques	Explicit and tacit	0	0%
No data on tie content	-	5	12.19%

Table 7.11 presents the various subject areas discussed in this case study. 39.02% of all knowledge transfers discussed materials, which makes it by far the

most discussed subject on this project. 17.07% of the transfers debated a combination of all three subjects, followed by techniques combined with technologies with 14.63%.

This outcome is most likely caused by a continuous problem with materials during this construction project. The main DGNB assessor Phy1/Aud1 elaborated on this during the interview as follows:

> *'One of the main problems in this construction project was to fulfil the DGNB requirements regarding sustainable materials. Most construction companies could not differentiate between the various sustainability levels of the products. Some even did not build in the materials that were requested in the tendering documents. As the architect's workload seemed to be high, he/she was too busy to check on all materials on-site. As a result the tests that were conducted after project completion revealed several not sustainable materials were built in that had to be changed.'*

An interesting point to make here is that the combination of materials and techniques is completely missing. This outcome is very surprising as it is in complete contrast to the results of the UK case studies and to the presumption, i.e. new sustainable materials might need new techniques for their installation. This issue will be discussed further in Chapter 8.

Nevertheless, since the most discussed subject area was sustainable materials it also gives further indications on the knowledge type transferred and thus can be linked back to the tie characteristics and network density. As argued in section 5.3.1 the new knowledge on sustainable materials only is considered to be explicit. Hence it can be better transferred through a sparse network with weak ties (Fernie *et al.,* 2003). This is in accordance to the finding above, i.e. materials being by far the most discussed subject area. However, the new knowledge on techniques was defined as tacit in section 5.3.1 and was part of in total 39.01% of all KTs. Therefore the relatively large amount of transferred tacit knowledge is an interesting finding and could indicate strong ties in this rather sparse network, though it is not as large as in the previous case studies. As Augier and Vendelø (1999) put forward that tacit knowledge is best transferred through strong ties. This is also supported by Granovetter (1973) and Fernie *et al.* (2003), as discussed in section 4.4.2. Strong ties can be defined by long, close relationships with high trust (Granovetter, 1973). Therefore the results on the knowledge sources in section 7.2.3.7 provide further insights into this matter.

7.2.3.5. Relationship between Tie Contents and the Actor Attribute Job Level

In order to determine whether knowledge on certain subject areas is more in demand by a particular workforce group, cross tabulation was carried out between tie contents and job level. The results are summarised in Table 7.12 and show the job level of the person who asked for advice on sustainable construction. Although operatives did not actively take part in this research, supervisors and professionals stated the subject areas they were questioned about by operatives.

Table 7.12: Tie Contents of Knowledge Transfers linked with Actor Attribute Job Level in Case Study Germany1

	No data on tie content	Materials	Technologies	Techniques	Materials and Technologies	Materials and Techniques	Techniques and Technologies	All three subject areas	Total
Operative	0%	33.3%	0%	33.3%	0%	0%	33.3%	0%	100%
Supervisor	16.6%	50%	8.3%	16.6%	8.3%	0%	0%	0%	100%
Professional	11.5%	34.6%	3.8%	0%	3.8%	0%	19.2%	26.9%	100%

Table 7.12 indicates that the most discussed subjects for each job level were:

- Operatives → Materials; Techniques; Techniques and Technologies
- Operatives' Supervisors → Materials
- Professionals → Materials; All three subjects combined

These findings are interesting as all three job levels are mostly concerned about the 'what' in terms of new sustainable building materials. This outcome is in line with the statement of the DGNB assessor, that most sub-contractors had problems with choosing the correct sustainable material. This aspect will be further examined in the other two German case studies, in order to investigate whether this phenomenon reappears. Furthermore this result indicates that there is no significant difference in tie contents depending on the job level of the actor. Therefore these variables seem to be not linked in this case study.

7.2.3.6. Relationships between Centrality Measures and the Actor Attributes Job Level and Age

This section explores the centrality measures of the nodes in this network. Figure 7.11 shows the same network map as before, but with a focus on the node sizes. The node sizes represent the average degree centrality of the actors, i.e. the larger the node the more central the actor in relation to KT on sustainable construction.

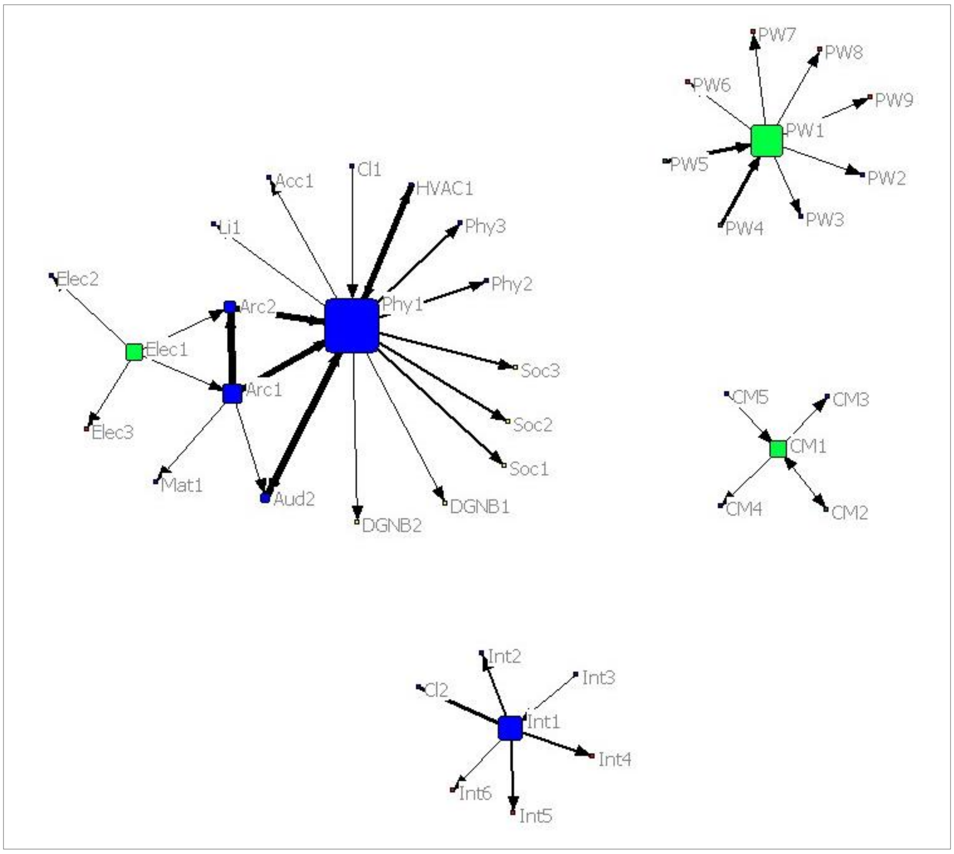


Figure 7.11: Knowledge Transfer Network of Case Study Germany1 – Degree Centrality

In order to support Figure 7.11 Table 7.13 presents the five most central actors for in-degree and out-degree centrality and their respective other value. As previously stated, a high in-degree value identifies a perceived expert on sustainable construction, while a high out-degree value shows a knowledge consumer or gatekeeper.

Table 7.13: Centrality Measures in Case Study Germany1

Actor	In-Degree	Actor	Out-Degree
Phy1/ Aud1	17	Phy1/ Aud1	27
Arc2	10	Arc1	11
PW1	6	Int1	10
Aud2	6	PW1	6
HVAC1	4	Aud2	5
Arc1	1	Arc2	4
Int1	1	HVAC1	3

It is important to investigate whether there is a link between the in- and out-degree centrality values and the actor attributes job level and age, as shown below.

Perceived experts:

- Phy1/Aud1, professional / DGNB assessor and building physics, age group: 45-54
- Arc2, professional / architect (also client), no data on age
- PW1, supervisor / plasterworks, age group: 25-34
- Aud2, professional / DGNB assessor, no data on age
- HVAC1, professional / HVAC and plumbing, no data on age

Knowledge consumers or brokers:

- Phy1/Aud1, professional / DGNB assessor and building physics, age group: 45-54
- Arc1, professional / architect (also client), age group: 45-54
- Int1, professional / interior fittings, age group: 35-44
- PW1, supervisor / plasterworks, age group: 25-34
- Aud2, professional / DGNB assessor, no data on age

Central actors are an interesting point in this network, as the larger network component concentrates around Phy1/Aud1, who is the building physician and also the main DGNB assessor. Aud2 is the second DGNB assessor, which explains the very frequent exchange in both ways between Phy1/Aud1 and Aud2. Nevertheless Aud2 is evidently not as integrated in this network as Phy1/Aud1. There are several reasons for this. First Phy1/Aud1 was a research participant, while Aud2 was not. Secondly Aud1 has two job roles in this construction project as he is also the building physician. Additionally Aud2 is only the second and not the main sustainability assessor. Moreover the office of Phy1/Aud1 is in the same city as the construction project, while the office of Aud2 is about 40 km away.

Obviously the main assessor Phy1/Aud1 transfers a lot of knowledge to different participants and receives knowledge mainly from Arc1 and Arc2, who represent the architects and clients at the time in this project. This is mainly due to the actor being employed as the sustainability expert. He receives and transfers various combinations of all three subject areas. Nevertheless this research finding is interesting, as it might imply a need for an additional sustainability expert to facilitate the knowledge flow, as discussed in the previous case study.

PW1 and Int1 are only in a central position in a smaller component, which is most likely due to them being research participants.

As shown in Table 7.13, Phy1/ Aud1, PW1 and Aud2 possess both high in-and out-degree values. This could indicate that these three actors are gatekeepers, as described in Chapter 4 or experts in one area and consumers in another. The following betweenness centrality calculations in Table 7.14 explore this issue further. Gatekeepers are important in this study as they pass on the knowledge on sustainable construction.

Table 7.14: Betweenness Centrality Measures in Case Study Germany1

Actor	Betweenness
Phy1/Aud1	65
PW1	12
Arc1	7.5
Arc2	5.5
CM1	5

Table 7.14 shows that the main gatekeepers in this network are:

- Phy1/Aud1, professional / DGNB assessor and building physics
- PW1, supervisor / plasterworks
- Arc1, professional / architect (also client)
- Arc2, professional / architect (also client)
- CM1, supervisor / construction management

These five actors had a high centrality value as well. In fact, Phy1/Aud1 and PW1 had such a high in- and out-degree centrality that it already suggested that they are gatekeepers, which is confirmed by the betweenness values. The large difference in the betweenness centrality values of Phy1/Aud1 and PW1 are probably caused by the job role of Phy1/Aud1 as the sustainability assessor. In addition it has to be considered that PW1 and CM1 are only central actors in two of the smaller components and not part of the main component. Arc1 has an in-degree centrality value of 1 and an out-degree value of 11 which renders him/her rather as a knowledge consumer. In addition Arc2 had a high in-degree value, which identified him as a perceived expert on sustainable construction.

7.2.3.7. Knowledge Sources

This section explores the knowledge sources further, i.e. their role and what kind of relationship exists between the knowledge source and receiver, and why this person was chosen to ask for advice on sustainable construction. Please see sections 3.4.1 and 5.3.1 for the discussion on knowledge repositories and sources. The results were analysed with content analysis and are summarised in Table 7.15. In total the participants provided this information for 44 knowledge transfers, thus the number in the right hand column is the count.

Table 7.15: Knowledge Sources in Case Study Germany1

Coding	Total
Supply chain member	8
DGNB contact	7
Colleague (on this project)	6
Client (=Architect)	6
Colleague (from another company)	5
Supervisor	4
Colleague (on another sustainable project)	4
Assessor	3
Friend	1
Total	**44**

As you can see in Table 7.14 the most common knowledge sources on this project were supply chain member (8), DGNB contact (7), colleague on this project (6) and client (6), all nearly on the same level. This is a much diversified finding on this question compared to the other case studies. The qualitative data showed that supply chain companies were without exception contacted in order to clarify questions on sustainable materials. In addition it was argued that *materials* is also the most discussed subject area in this case study. Hence the previously mentioned issue of sustainable materials re-appears and influences the choice of knowledge sources as well.

Respondents elaborated further why they preferred to ask this specific person for advice on sustainable construction. In 11 out of 44 KTs the knowledge sources were contacted because they were in charge. Knowledge and experience were the only other reasons named by the respondents in this case study. Literature (e.g. Berends, 2005) confirms that the perceived competency of individuals by other team members, termed 'transactive memory' (see section 3.4.1.2), is one of the reasons for well-performing teams. As the transactive memory develops over time and experience with working together, this finding approves that in order to get work related advice most people ask their supervisor or colleague. Hence, advice is generally rather sought inside the immediate work team, than outside, i.e. in other project participating companies. This view is also supported by Sun and Scott (2005) and confirmed by others, such as Argote and Ingram (2000).

In addition it was further examined, whether the previously identified perceived experts and knowledge consumers differ in their knowledge source choice. The following list shows who they prefer to ask.

Perceived experts:

- Phy1 colleague, assessor, DGNB
- Arc2 no data
- PW1 supervisor, field crew
- Aud2 no data.
- HVAC1 no data

Knowledge consumers or brokers:

- Phy1 colleague, assessor, DGNB
- Arc1 friend, assessor, materials tester
- Int1 supplier, manager
- PW1 supervisor, field crew
- Aud2 no data

The findings on this issue are much diversified. Colleague and supplier were mentioned by two actors. Moreover field crew, materials tester and friend were declared to be knowledge sources. This outcome could indicate that there is a difference in the knowledge sources depending on actor centrality, thus a link.

7.2.3.8. Relationships between Knowledge Transfer Methods and the Actor Attributes Age, Job Level and Actor Centrality

Regarding the KT methods especially for explicit knowledge in terms of achieving the sustainability goal of this case study the Phy1/Aud1 mentioned in the interview a general lack of understanding of the DGNB requirements for documentation and evidence. For instance he stated that '*requirements for documents and providing evidence, particularly for writing the report are unclear.*' Furthermore the assessor suggested 't*he DGNB should have a contact platform for contractors to inquire information about the various sustainability levels of materials.'* Interestingly these statements are similar to the one made by the sustainability manager of case study UK2 and will be further discussed in Chapter 8.

The methods used to seek knowledge and those to receive it were investigated. No research participant in this case study has added any method, which might suggest that all the important methods were covered in the data collection tools. Figure 7.12 presents the findings on this issue.

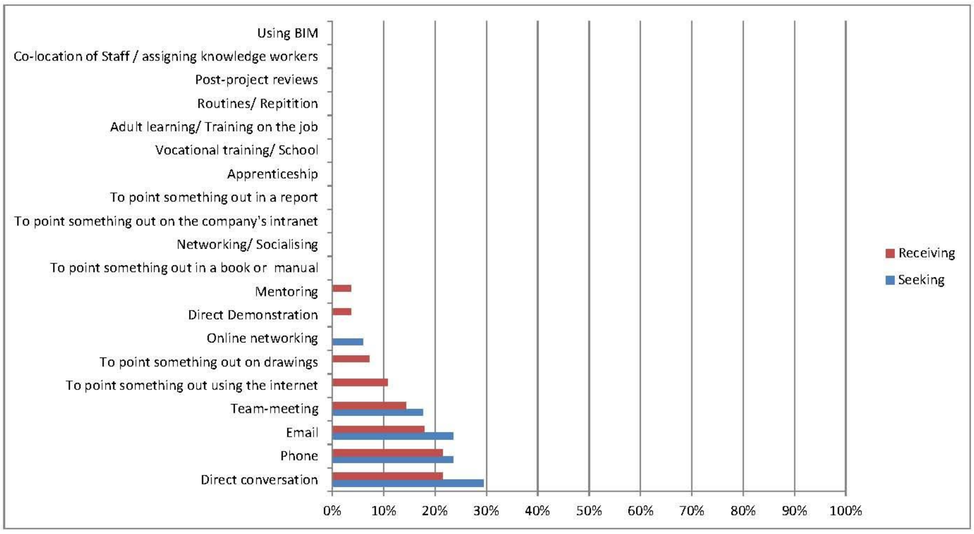


Figure 7.12: Knowledge Transfer Methods when seeking and receiving Knowledge in Case Study Germany1

Figure 7.12 shows that the participants sought knowledge on sustainable construction mostly by using direct conversation. This is followed by phone, email and team meetings. Only a small amount of questions were asked during online networking.

Most of the knowledge given was transferred using the same methods, i.e. direct conversation, phone, email, team meetings and internet. As it could have been assumed for construction industry, this is followed by pointing something out on drawings and direct demonstration. A small amount of knowledge on sustainable construction was also received through mentoring.

Therefore the eight methods used in this case study were:

- Direct conversation
- Phone
- Email
- Team meeting
- To point something out in the internet
- To point something out on a drawings
- Direct demonstration
- Mentoring

Most of these methods are according to literature (Haldin-Herrgard, 2000; Egbu, 2004) used to transfer tacit knowledge. As a result the choice of these KT methods gives further indications to the tie contents. As discussed in section 7.2.3.4, tacit knowledge was part of 39.01% of all the knowledge transfers that occurred. Thus this selection of KT methods provides further evidence to this relatively large amount of transferred tacit knowledge.

A remarkable finding is that in this case study not all methods were used to receive knowledge on sustainable construction. This could mean that a small selection of methods was enough to transfer the knowledge on sustainable construction. However, the small sample size has to be considered here as well. Hence it is difficult to make a statement on this matter. Nonetheless since most discussions in this case study seem to evolve around sustainable materials it seems odd that manuals or reports are not being used to seek advice. The following methods were not used at all:

- BIM
- Co-location of staff / knowledge workers
- Post-project reviews
- Routines/ repetition
- Adult learning/ training on the job
- Vocational training / school
- Apprenticeship
- Reports
- Intranet
- Networking/ Socialising
- Books/ Manuals

In order to investigate whether different methods are chosen depending on age groups or job level, the following figures present the cross tabulation of these. As only eight methods were used for the transfer of knowledge the calculations focus on these.

Figure 7.13 shows the cross tabulation between 'age group' and the chosen methods to transfer knowledge. There is indeed a difference in the chosen KT methods depending on the age of the actors. Mentoring is preferred by the age group 35-44, direct demonstration by the age group 25-34 and drawings by the group of 25-34. This suggests a link between these two variables. As argued in section 3.4.2.5, Riege (2005) states that age differences of participants influence KT. The findings show that this could be due to for instance preferring to use different methods to transfer knowledge.

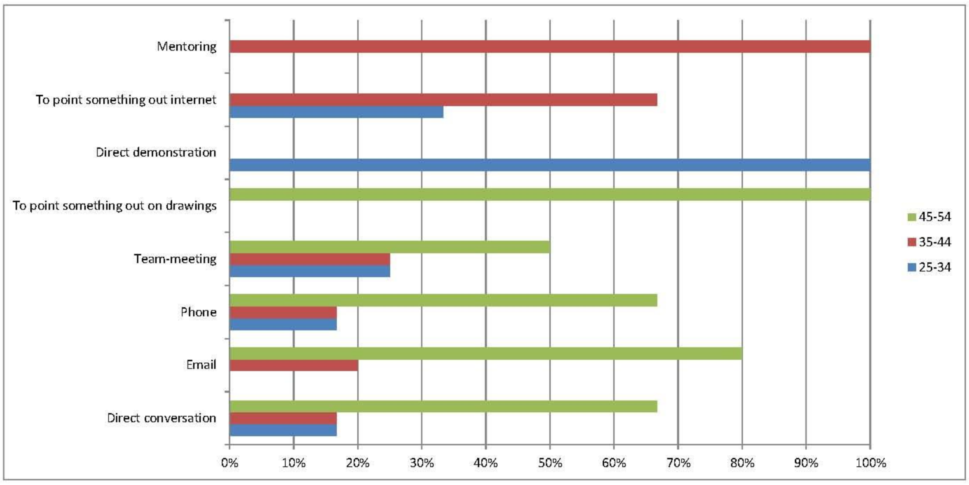


Figure 7.13: Knowledge Transfer Methods Cross Tabulation with Age Groups in Case Study Germany1

Figure 7.14 presents the cross tabulation between 'job level' and the chosen KT methods. Apart from three methods both job levels used all methods. Only direct demonstration was preferred by supervisors. This is clearly because of their job description in terms of supervising operatives. Professionals preferred mentoring and pointing something out on drawings. Therefore this indicates a link between chosen KT methods and job level. Section 3.4.2.5 argued that the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which could also inhibit KT.

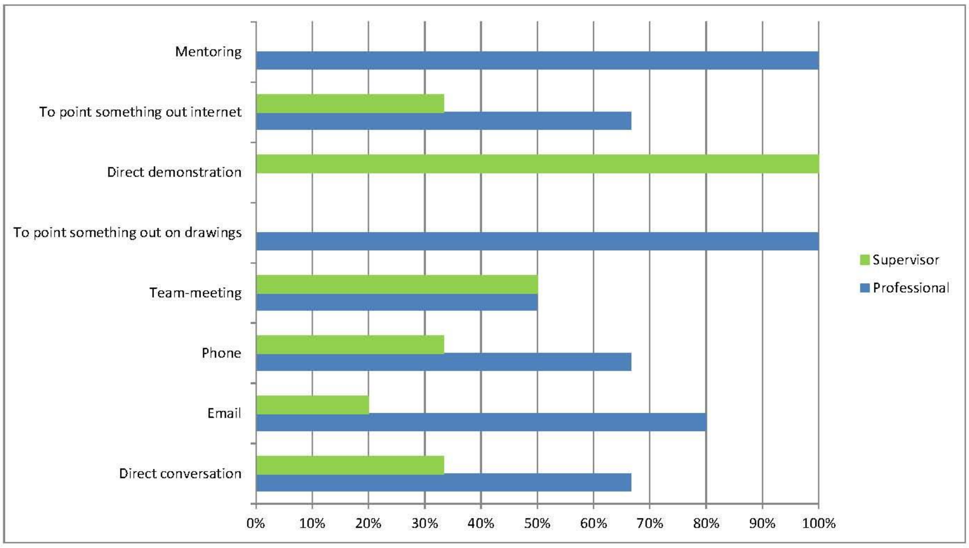


Figure 7.14: Knowledge Transfer Methods Cross Tabulation with Job Level in Case Study Germany1

In the previous section 7.2.3.7 the following five actors were identified as the ones with the highest in-degree centrality values, i.e. are perceived by other actors as experts on sustainable construction. Unfortunately Arc2, Aud2 and HVAC1 were no active research participants, but named by others. As a result there is no data on their preferred KT methods.

- Phy1, professional → Direct conversation, team meeting, telephone, email
- Arc2, professional → n.a.
- PW1, supervisor → Direct conversation, team meeting, telephone demonstration
- Aud2, professional → n.a.
- HVAC1, professional → n.a.

The data provided by the remaining two perceived experts Phy1 and PW1 shows they preferred to use KT methods rather according to their job level, i.e. in line with the results for the overall job levels presented in Figure 7.14. As a result this leads to the assumption that the link between KT methods and 'job level' seems to be stronger that the one with actor centrality.

7.2.3.9. Duration of Knowledge Transfer

Table 7.16 shows the results on the duration of the KTs occurred.

Table 7.16: Duration of Knowledge Transfers in Case Study Germany1

Time in Minutes	Count	Percentage
1	6	20%
2	4	13.3%
5	4	13.3%
10	14	46.7%
20	1	3.3%
60	1	3.3%

The results for this case study show that most knowledge transfers (46.7%) take about 10 minutes, while most others (46.6%) are up to ten minutes and only the remaining 6.7% are between 10 and 60 minutes. It is thought that this aspect is of importance since construction projects are usually under a certain time pressure. Previous studies stated that participants have argued with a general lack of time, respective the length of time that it would take to give advice as a reason for KTs not to take place (Hansen, 2002; Riege, 2005; Lu, Sexton, 2007). However, this result shows that it only takes on average about ten minutes to answer questions on this matter. Hence this finding could prove that this small amount of time might be worthwhile, if it leads to an overall better built outcome.

7.2.4. Conclusion

This section presented the data analysis of the first German case study. It first provided a brief overview of the research settings and the general actor attributes of the research participants. Thereafter it was investigated to what extent the actor attributes and social network characteristics relate to each other and influenced the KT on sustainable construction in this case study. The construction project was located in the South-West of Germany and already finished at the time of data collection. As a result only a total of 6 questionnaires were collected, in addition to one interview. Moreover only professionals and supervisors participated in this research project. This limited the quality of the data and thus the findings. Following are the main results for this case study.

Table 7.17: General Factors and Social Network Characteristics influencing KT on sustainable Construction in Case Study Germany1

	Awareness	Perceived Use of sustainable Material/ Technology	Training Received	Perceived Training Need	KT Methods	KT Source	Network Density	Job Level	Age
Age	NP	x	NP	x	√	NP	n/a	n/a	n/a
Gender	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Nationality	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Education	Linked to job level								
Job level	NP	x	NP	x	√	√	n/a	n/a	n/a
Tie Contents	n/a	n/a	n/a	n/a	√	NP	√	x	n/a
Actor Centrality	NP	NP	√	NP	x	√	n/a	NP	x
Awareness	n/a	NP	n/a	n/a	n/a	√	n/a	NP	NP

√ - linked; x – not linked; NP – link not prominent enough; n/a – not applicable/ investigated

In summary many of the detected links were not prominent enough in comparison to the other case studies due to the quality of the data, as stated above. Table 7.17

provides an overview of the findings, which will be explained in the succeeding paragraphs.

In relation to so-called general influencing factors, such as gender and nationality, no remarkable results have been detected due to the nature of the sample, i.e. all participants were male and German. Yet, as stated in section 3.4.1.1, some respondents might have a multi-cultural background, which was not fully captured by the data collected on nationality. Moreover the finding in section 7.2.2.2 confirmed that education defines job level later in life, hence these two actor attributes are linked. As a result succeeding analyses were conducted for job level only, but the findings represent educational background as well.

Furthermore 100% of the respondents in this case study were aware that the construction project strived to achieve a DGNB certificate. This result can be considered as exceptionally high and is probably due to the job levels of the respondents. As a result it was not possible to investigate any links between awareness and other variables.

Out of all respondents only 33.3% stated that they have had special training on sustainable construction, while no one acknowledged the requirement of such specific skills. This finding is also exceptional. Nonetheless the participants most likely did not feel the need for special training, as they were already very knowledgeable, shown through the high level of awareness. Those who actually received a specialised training were professionals and stated that it was an auditor/ assessor training arranged by the DGNB organisation.

In regards to social network characteristics, the size of this network is with 38 nodes relatively small. It has a network density of 0.0532, hence is rather sparse than cohesive. In terms of KT on sustainable construction this means, as previously discussed, that weak ties might limit the exchange of tacit knowledge according to literature. The new knowledge on sustainable materials only is considered to be more explicit and was the most discussed subject area (39.02%). Nevertheless the frequency of other tie contents, i.e. on techniques or combinations of subject areas shows that in 39.01% a combination of tacit and explicit knowledge was transferred through this rather sparse network. This finding can be seen as significant as it is already the third case study in this research project where this occurs, though the percentage is not as high as in the other case studies. In addition, a link between tie contents and KT methods was detected, as the most frequently used KT methods indicate the transfer of tacit knowledge. It was argued in the two UK case studies that it might have been a sparse network but with strong ties facilitating the transfer of tacit knowledge (Granovetter, 1973). This could be identified through the relationship to the knowledge sources, i.e. colleagues indicating a potential trust based, long relationship. The main knowledge sources in this case study were supply chain members, DGNB contacts, colleagues on the same project and the client, all nearly at the same level.

Centrality measures showed which actors are perceived as experts on sustainable construction by others and which only consume knowledge. Phy1/Aud1, the main DGNB assessor and building physician of this construction project is the most central actor and was also identified as the main gatekeeper. This result is similar to UK2 and might suggest employing a sustainability manager or assessor as a contact person for queries on sustainable construction throughout the project.

No research participant has added any KT method. However, this is the first case study where not all offered methods were used. Nonetheless a link between the age groups and the chosen KT methods was detected. Mentoring is preferred by the age group 35-44, direct demonstration by the age group 25-34 and drawings by the group of 25-34. As argued in section 3.4.2.5, Riege (2005) states that age differences of participants influence KT. The findings show that this could be due to for instance preferring to use different methods to transfer knowledge. Moreover a link between the choice of KT methods and job level was found although not very prominent. Apart from three methods both job levels used all methods. Direct demonstration was preferred by supervisors. This is clearly because of their job description in terms of supervising operatives. Professionals preferred mentoring and pointing something out on drawings. Section 3.4.2.5 argued that the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which could also inhibit KT. Additionally the findings showed that most central actors do not use different or more methods than others, but rather according to their job level. Therefore there seems to be no link between actor centrality and KT methods in this case study.

This case study also collected data on the duration of the KTs. The findings show that most KTs only require up to 10 minutes (46.7%) while most others (46.6%) are divided into one, two and five minutes and only the remaining 6.7% are between 10 and 60 minutes. This suggests that this relatively small amount of time might be worthwhile if it improves the quality of the built outcome.

The next part of this chapter presents the findings of the second German case study.

Key for Case Study Germany1

indicates research participants

Trade	Code	Job Level	Code
Architect	Arc	Professional	Arc1
		Professional	Arc2
Construction	CM	Supervisor operatives	CM1
		Operative	CM2
		Professional	CM3
		Professional	CM4
		Professional	CM5
Electrical Contractors	Elec	Supervisor operatives	Elec1
		Professional	Elec2
		Supply chain member	Elec3
Plaster works	PW	Supervisor operatives	PW1
		Professional	PW2
		Professional	PW3
		Operative	PW4
		Operative	PW5
		Supply chain member	PW6
		Supply chain member	PW7
		Supply chain member	PW8
		Supply chain member	PW9
Physics/Auditor	Phy	Professional	Phy1/Aud1
		Professional	Phy2
		Professional	Phy3
Interior fittings	Int	Professional	Int1
		Professional	Int2
		Professional	Int3
		Supply chain member	Int4
		Supply chain member	Int5
		Supply chain member	Int6
Auditor no 2	Aud	Professional	Aud2
Material check-up	Mat	Professional	Mat1
HVAC + plumbing	HVAC	Professional	HVAC1
Client/ Landlord	CL	Professional	Cl1
		Professional	Cl2
Lighting	Li	Professional	Li1
Accustics	Acc	Professional	Acc1
Contacts outside the project	DGNB	Professional	DGNB1
		Professional	DGNB2
	Soc	Colleauges from DGNB training	Soc1
		Colleauges from DGNB training	Soc2
		Colleauges from DGNB training	Soc3

7.3. Case Study Germany 2 – Hamburg

7.3.1. Research Setting

The construction project was a prime office scheme located in Hamburg. The €60m project covers approximately 22,710 square metres and was carried out by a main contractor. Construction started in 2011, with project completion planned for 2013. The project received a gold DGNB pre-certificate. A total of 21 questionnaires and a small set of participant observation data were collected, mainly in an on-site office.

The project achieved the following scores in the six main criteria groups of the DGNB certificate discussed in section 2.4.3.

Table 7.18: Sustainable Performance of Project Germany2

Categories	**Score**
Overall quality of the building	81.6%
Ecological Quality	78.0%
Economic Quality	81.3%
Sociocultural and functional quality	87.4%
Technical quality	75.3%
Quality of the process	91.9%
Quality of location	84.8%

7.3.2. Actor Attributes

This section outlines the respondents' so-called actor attributes and investigates their relationships, if any.

7.3.2.1. Age, Gender and Nationality

Figure 7.15 shows that the age range of the research participants in this case study was very diverse with 4.8% between 16 and 24, 28.6% between 25 and 34, and 38.1% between 35 and 44. 19% of the participants were between 45 and 54, and 9.5% between 55 and 64. As illustrated in Figure 7.16 the majority of respondents were male (90.5%). In addition, practitioners from four different countries participated in this research, i.e. Germany (85.7%), Angola (4.8%), Austria (4.8%) and Ukraine (4.8%) (see Figure 7.17). As most respondents were

German and male, no remarkable results were found in cross tabulations with these variables. Yet, as stated in section 3.4.1.1 this result might be limited to fully capture the multi-cultural background of some respondents. As a result age group was singled out of these three variables for succeeding analyses.

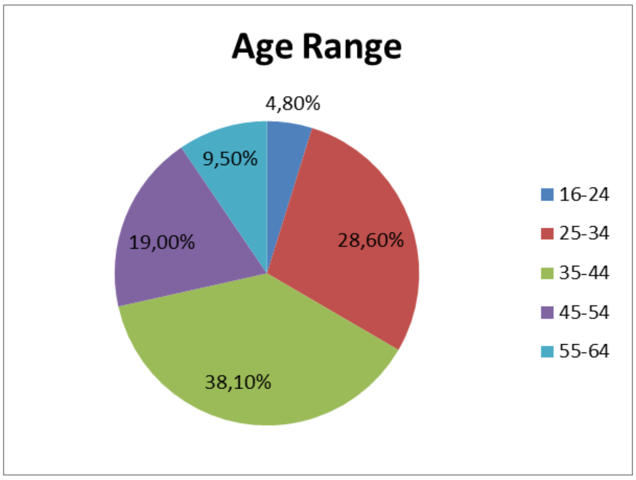


Figure 7.15: Age Range of Research Participants in Case Study Germany2

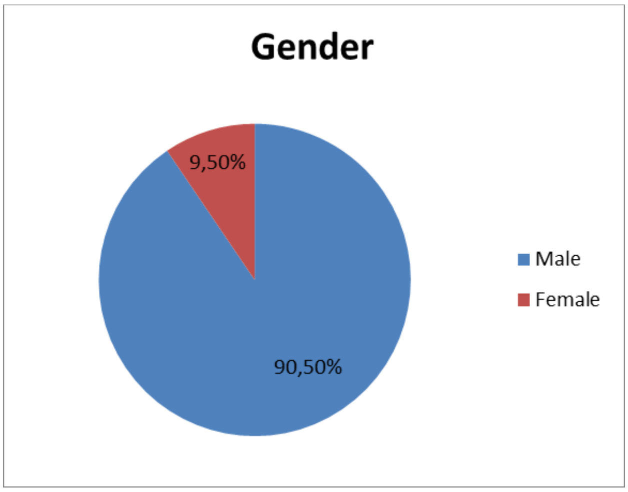


Figure 7.16: Gender of Research Participants in Case Study Germany2

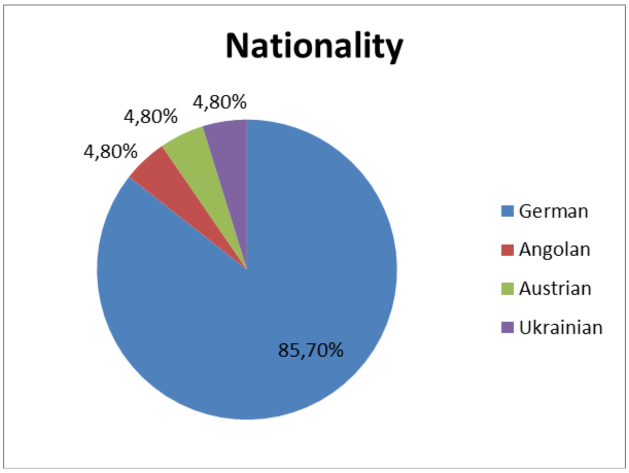


Figure 7.17: Nationality of Research Participants in Case Study Germany2

7.3.2.2. Educational Background and Job Levels

The educational background of the research participants, depicted in Figure 7.18 varied from 5% with no education or job training, 60% had completed an apprenticeship, and 35% a Diplom. Please see section 7.2.2.2 for more details on the German degree system. Figure 7.19 illustrates that this case study included participants from all four job levels, i.e. apprentices (5%), operatives (35%), operatives' supervisors (25%) and professionals (35%).

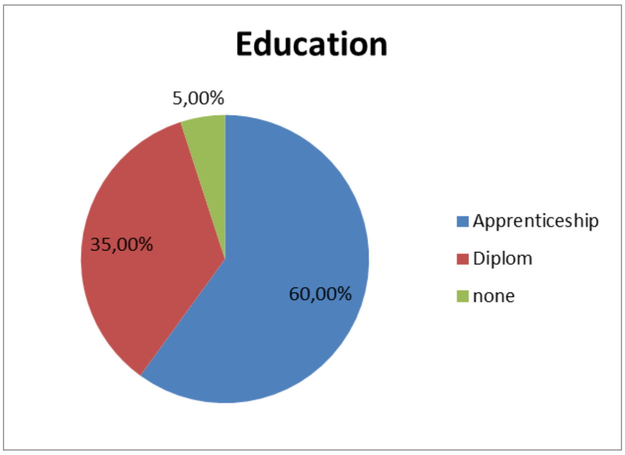


Figure 7.18: Educational Background of Research Participants in Case Study Germany2

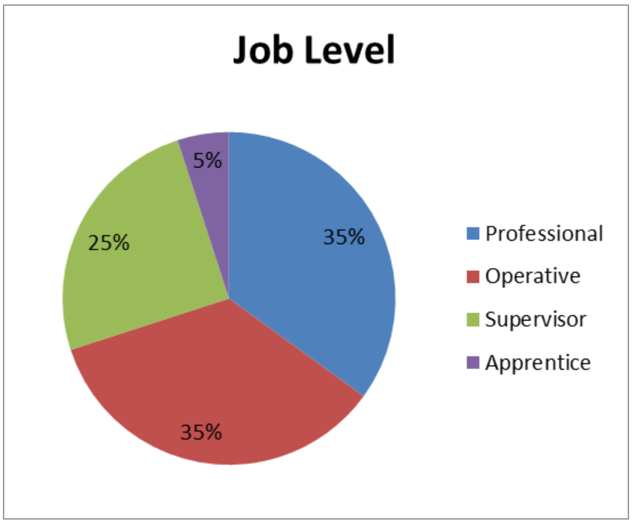


Figure 7.19: Job Level of Research Participants in Case Study Germany2

The cross tabulation presented in Table 7.19 confirms the strong relationship between ‘educational background’ and ‘job level’, as expected. As a result the succeeding analyses in this case study will equate educational background with job level. Thus bivariate analyses conducted for job level only stand for both variables.

Table 7.19: Cross Tabulation between educational Background and Job Level in Case Study Germany2

	Job Level				**Total**
Educational Background	Professional	Supervisor	Operative	Apprentice	
None	0	0	0	1	1
Apprenticeship	0	5	7	0	12
Diplom	7	0	0	0	7
Total	7	5	7	1	20

7.3.2.3. Awareness of Sustainability

Figure 7.20 indicates that 71.4% of the respondents in this case study were aware that this construction project strived to achieve a DGNB certificate. This result is considered to be relatively high compared to the other case studies. This finding can be explained by statements from three respondents, who confirmed that ‘*the various contractors are made aware of it through tendering documents and contracts.’*

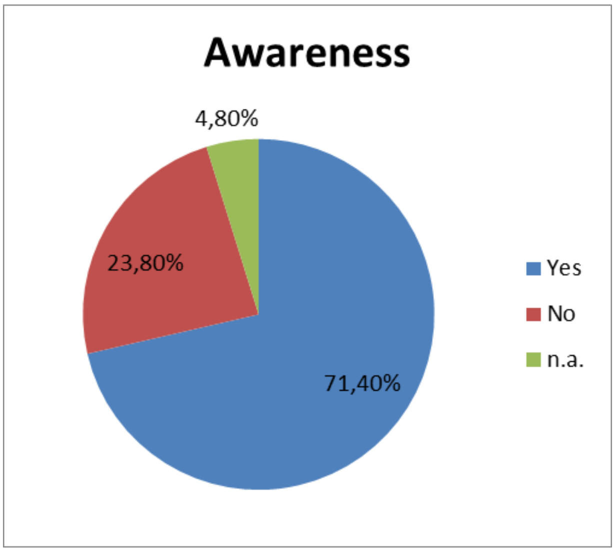


Figure 7.20: Awareness of Sustainability of Research Participants in Case Study Germany2

When investigating this matter further it was found that levels of awareness of sustainability are spread throughout the various age groups (see Table 7.20). Thus it is clear that there is no link between these two variables.

Table 7.20: Cross Tabulation between Awareness and Age Group in Case Study Germany2

	Awareness			Total
Age Group	**Yes**	**No**	**Not ticked**	
16-24	0	1	0	1
25-34	4	2	0	6
35-44	7	0	1	8
45-54	3	1	0	4
54-65	1	1	0	2
Total	15	5	1	21

Table 7.21 shows that the only five research participants, who were not aware of the sustainability target of this project, were operatives and the apprentice. Thus this finding indicates a link between awareness and job level. Curiously, the same apprentice stated that he/she had actually received specialised training. He/she elaborated further on this by stating that *'this was part of earlier vocational training on garden landscaping.'* This respondent seems to mistakenly link garden landscaping with sustainability, because it is related to the environment.

Table 7.21: Cross Tabulation between Awareness and Job Level in Case Study Germany2

	Awareness		**Total**
Job Level	Yes	No	
Professional	7	0	7
Operative	3	4	7
Supervisor	5	0	5
Apprentice	0	1	1
Total	15	5	20

CM5, a professional from the construction management company elaborated further on this and recommends the following to enhance KT on sustainable construction:

> *'It would be great if most project participants were to possess broader knowledge of sustainable construction, but due to capacity we only have a few specialised people. As a result most practitioners only possess a basic level of knowledge of sustainable construction. Moreover it is very difficult to make the builders aware of this issue, as some of them do not even speak the same language.'*

Here the actor attribute 'nationality' is mentioned as a potential barrier for a successful KT on sustainable construction. This is in line with Riege (2005) who put forward that differences in national culture impede KT. Moreover Egbu (2004) argues that a shared language is important for a successful KM process. Nonetheless, as most research participants were Germans in this case study this matter could not be further examined.

7.3.2.4. Perceived Use of Sustainable Materials and Technologies

Figure 7.21 summarises the responses to the question whether the research participants were aware, if their companies use any sustainable material or technology. Only 38.1% of the answers were positive. Here it is interesting that 42.9% of the respondents did not know whether they used such materials or technologies.

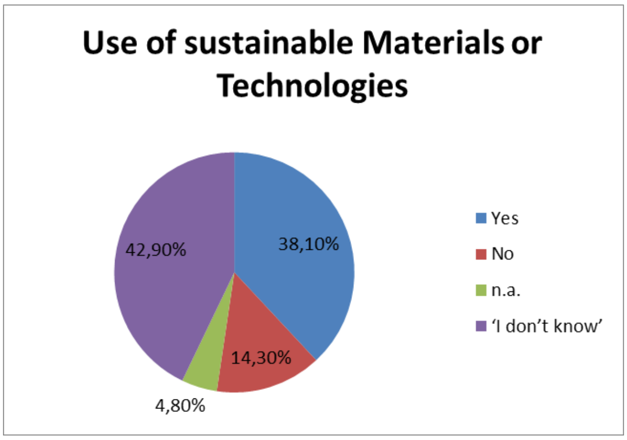


Figure 7.21: Perceived Use of sustainable Materials/ Technologies in Case Study Germany2

The cross tabulation presented in Table 7.22 confirms the relationship between the perceived use of sustainable materials and job level, as the operatives and the apprentice were not aware of such use.

Table 7.22: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Job Level in Case Study Germany2

	Perceived use of sustainable materials and technologies			Total
Job Level	Yes	No	I do not know	
Professional	5	2	0	7
Operative	0	1	5	6
Supervisor	3	0	2	5
Apprentice	0	0	1	1
Total	8	3	8	19

The project manager in charge stated that *'operatives need more definitions of sustainable materials.'* This might explain why the awareness of the use of sustainable materials or technologies is relatively low in this job/education group. Moreover it suggests that it would have been worthwhile to inform operatives better on the specific materials and technologies used in this project due to the sustainability aim. Nonetheless a supervisor argued that *'the decision about which materials are used is made during the design stage and not at all affected by the installation. As soon as we get the information on which materials to use, we inform ourselves on their installation techniques and install them.'* This statement implies that the process is rather learning by doing than thought-out.

The following cross tabulation shows that there is no link between the perceived use of sustainable materials and age in this case study.

Table 7.23: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Age in Case Study Germany2

	Perceived use of sustainable materials and technologies			Total
Age Groups	Yes	No	I do not know	
16-24	0	0	1	1
25-34	2	0	4	6
35-44	3	2	3	8
45-54	3	0	1	4
55-64	0	1	1	2
Total	8	3	10	21

The respondents elaborated further on their use of sustainable materials and technologies which was analysed using content analysis, as explained in section 5.6.3. The results are summarised in Table 7.24. This data derives only from the respondents who elaborated further on this topic. This explains why the percentage of 'no use of sustainable materials' (7.14%) does not match the replies on 'companies' use of sustainable materials and technologies' (14.3%) in Figure 7.21.

The materials and technologies named by research participants are for the most part sustainable. Some confusion exists only for fire protection. This suggests that amongst those research participants who elaborated on this matter, there is a very high level of understanding and awareness about sustainable materials and technologies.

Table 7.24: Sustainable Materials/ Technologies as perceived by Research Participants in Case Study Germany2

Code	Count	Percentage
No actual usage due to nature of the job, i.e. professionals	1	7.14%
Reusable steel forms	2	14.29%
Geothermal energy system	1	7.14%
Photovoltaic	1	7.14%
Solar heat	1	7.14%
Rainwater harvest system	1	7.14%
Triple-glassing	1	7.14%
Eco-friendly prime coat for waterproofing the roof	1	7.14%
Insulation material	1	7.14%
Water pipe insulation	1	7.14%
Developing sustainable energy concepts	1	7.14%
Consulting on sustainable materials	1	7.14%
Fire protection	1	7.14%

One respondent claimed that his/her company does not use any sustainable material or technology indicating that this is due to the nature of the job, i.e. professional level. As is was decided during the research design process to use the same questionnaire for all job levels it often occurred that professionals misinterpreted this question in terms of the actual use, i.e. the installation of sustainable materials and/or technologies. Surely the professionals, e.g. architects are involved in the specification of the sustainable materials and technologies.

Table 7.25 compares the awareness of the sustainability goal of the project with the perceived use of sustainable materials and technologies. Out of 15 respondents who were aware only eight indicated the actual use of sustainable materials and technologies. Three ticked ‘no’ and four ticked ‘I do not know’. This might indicate that the question led to misunderstandings.

Table 7.25: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Awareness in Case Study Germany2

	Perceived use of sustainable materials and technologies			Total
Awareness	**Yes**	**No**	**I do not know**	
Yes	8	3	4	15
No	0	0	4	4
Not ticked	0	0	1	1
Total	8	3	9	20

7.3.2.5. Received and Required Training on Sustainable Construction

Figure 7.22 shows the training which has been received on sustainable construction techniques, while Figure 7.23 presents the perceived requirement for such training.

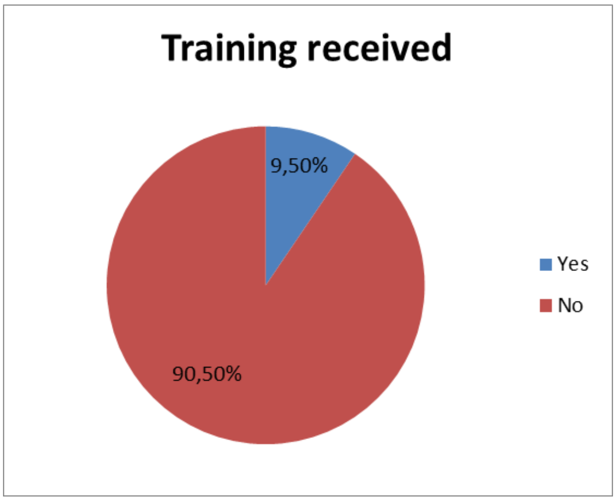


Figure 7.22: Training on sustainable Construction received by Research Participants in Case Study Germany2

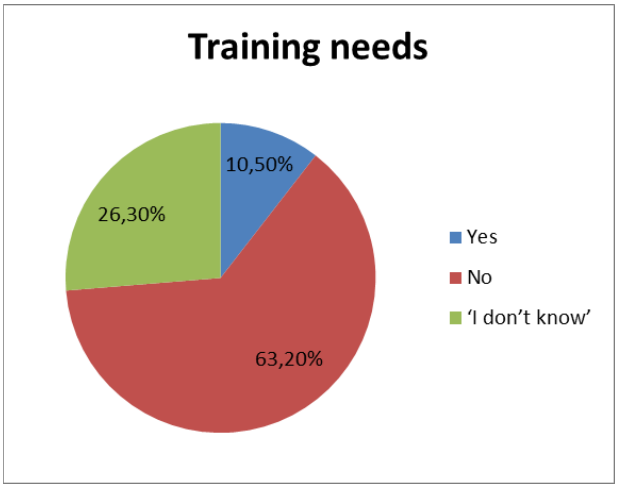


Figure 7.23: Perceived requirement for Training on sustainable Construction by Research Participants in Case Study Germany2

As indicated in Figure 7.22 and 7.23, out of all respondents only 9.5% stated that they have had special training on sustainable construction and only 10.5% acknowledged the requirement of such specific skills. These results are very low compared to the other case studies.

It was considered to be vital to further investigate whether there are any links between 'training' and 'age group', and 'training' and 'job level'.

Table 7.26: Cross Tabulation between received Training and Age Group in Case Study Germany2

	Received training		**Total**
Age Group	Yes	No	
16-24	1	0	1
25-34	0	6	6
35-44	1	7	8
45-54	0	4	4
54-65	0	2	2
Total	2	19	21

Table 7.27: Cross Tabulation between Training Needs and Age Group in Case Study Germany2

	Perceived training needs			Total
Age Group	**Yes**	**No**	**'I don't know'**	
16-24	0	0	1	1
25-34	0	3	2	5
35-44	1	6	1	8
45-54	1	2	1	4
54-65	0	1	0	1
Total	2	12	5	19

As depicted in Table 7.26 it is evident that the majority of research participants who did not receive any special training are within various age groups. Moreover 63.2% of the research participants, who were spread across the different age groups, did not consider such training necessary (see Figure 7.23). Hence age does not influence these issues in this case study.

Table 7.28: Cross Tabulation between Job Level and received Training in Case Study Germany2

	Received training		Total
Job Level	**Yes**	**No**	
Professional	1	6	7
Operative	0	7	7
Supervisor	0	5	5
Apprentice	1	0	1
Total	2	18	20

Table 7.29: Cross Tabulation between Job Level and Training Needs in Case Study Germany2

	Perceived training needs			Total
Job Level	Yes	No	'I don't know'	
Professional	1	6	0	7
Operative	0	2	3	5
Supervisor	1	3	1	5
Apprentice	0	0	1	1
Total	2	11	5	18

The majority of respondents in this case study (90.5%) did not receive any specialised training on sustainable construction and they are wide-spread throughout the various job levels, as depicted in Table 7.28. Table 7.29 presents a wide range of answers in relation to the question whether such training is actually required. Hence no link with job levels was detected. Nonetheless, this shows a general lack of agreement as to the necessity of such training.

In order to explore the issue of training and skills on sustainable construction further, the research participants were asked to elaborate further on the question what kind of training they received or why they had not received any. This information was analysed using content analysis, as presented in section 5.6.3. This data only derives from the respondents who elaborated further on this topic. The results are summarised in Table 7.30.

Table 7.30: Perceptions of sustainable Construction Training in Case Study Germany2

Code	Count	Percentage
1 day course in-house	2	15.38%
Vocational training	2	15.38%
I learnt everything through routines/ repetition/ experience	2	15.38%
No reason for training	2	15.38%
No time for training	2	15.38%
No training was offered	1	7.69%
First DGNB construction project	1	7.69%
DGNB Auditor and LEED AP	1	7.69%

Since at this case study the majority of respondents did not undergo any special training on sustainable construction the elaborations in Table 7.30 further illuminate this issue. Perhaps it is due to the fact that they have not had many opportunities to work on projects aiming for sustainability certificates to justify an investment on training. It could simply be that employers are expecting operatives to learn on the job, particularly where activities involve substitution of materials which do not have a high degree of novelty. Time constraints are a constantly emerging issue when it comes to training and KT throughout all case studies. The remaining comments made, do concern how participants received their knowledge on sustainable construction, and are therefore about KT methods. Hence they were particularly interesting in regards to testing the KT process box of the conceptual framework.

- Routines/ repetition/ experience
- 1 day course in-house

- Vocational training
- DGNB Auditor/ LEED AP training

Four of these five knowledge transfer methods above were already part of the conceptual framework presented in Chapter 5. Moreover, *DGNB Auditor/ LEED AP training* could be allocated to adult learning. Thus in terms of achieving the objective to test the conceptual framework in practice these statements were taken into account. It was investigated whether the results of the other case studies confirm this trend.

The next section examines the social network characteristics, their relationships and to what extent they influenced KT on sustainable construction.

7.3.3. Social Network Characteristics

Figure 7.24 illustrates the knowledge transfer network of this case study. The colour coding and line weights used are in accordance with the description provided in section 5.6.4. Please also see the key at the end of each case study for clarification of the figures within this chapter.

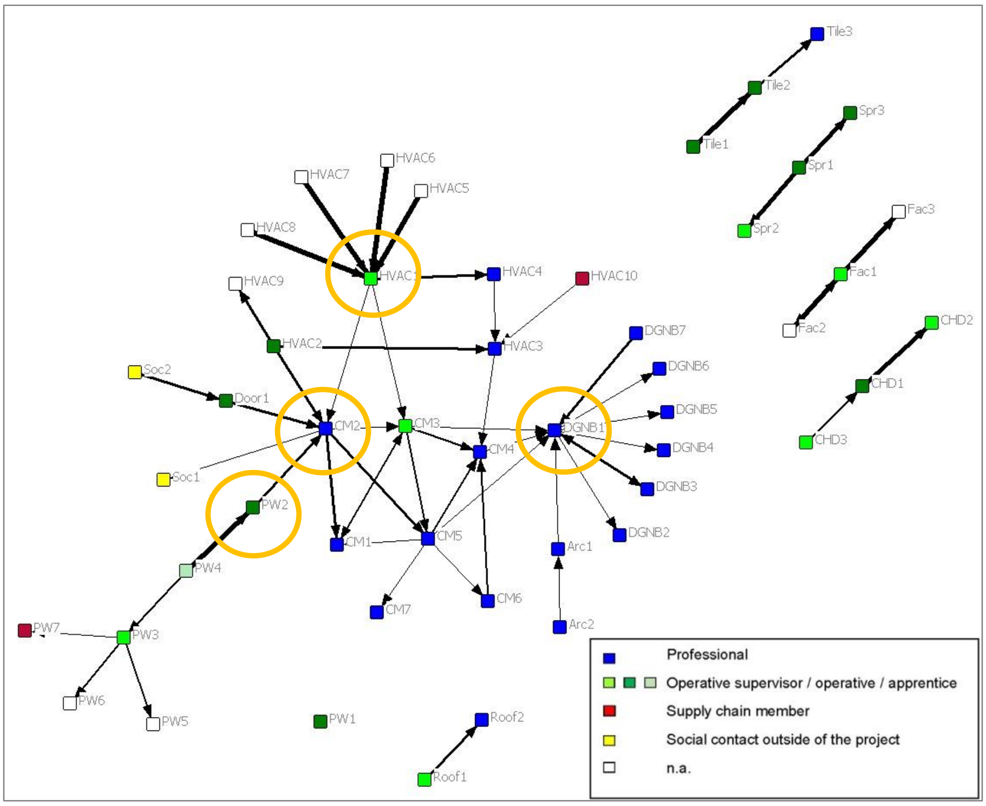


Figure 7.24: Knowledge Transfer Network of Case Study Germany2

7.3.3.1. Size of the Network

This network comprises of 50 nodes. As you can see in the fold-out key at the end of this case study, only 22 out of the 50 were research participants. The other 28 actors were named by them. Nevertheless, apart from the two social contacts, all actors were involved in the same construction project. As stated in section 5.5.2.1 the network boundary was defined as all participants involved with one particular sustainable office construction project. The sampling, which led to the selection of these 22 respondents, is presented in section 5.4.2.

7.3.3.2. Network Structure

The network structure consists of one main component on the left hand side, and five smaller components and one isolate, i.e. PW1, on the right hand side and the bottom of Figure 7.24. The main component includes the following companies: the architecture practice, the sustainability assessing company, the construction management company, the plaster works, the HVAC company and the steel door installers. The five small components each represent one company, i.e. tiler, sprinkler, façade installer, core hole driller and roofer.

As for the companies installing the sprinklers, conducting the core hole drilling and the tiling one could argue that their involvement with the other trades might not be as vital for the sustainable built outcome as for other companies, i.e. they might not require knowledge on sustainable construction from other project participants in order to fulfil their job, compared to for example construction contractors. This could therefore be the reason why they are not connected to the main component. Nevertheless the isolated network position of the façade company is unclear. Surely respondent behaviour is another reason for this network structure and particularly for operatives being in such central positions within the smaller components. As shown on the fold-out key at the end of this case study these actors (Tile2, Spr1, Fac1, CHD1) were all research participants.

The network position of the roofer company can be explained simply by respondent behaviour. Roof1 was in the middle of filling in the questionnaire when it started to rain heavily. As a result he/she had to abort the questionnaire and help the operatives to cover the roof. As the weather did not change again, it was not possible for Roof1 to complete the questionnaire.

PW1 is shown as an isolate, because he/she filled in the questionnaire, but left the SN questions blank and no one named him/her as a knowledge source on sustainable construction.

7.3.3.3. Cut-Points and Hierarchy Levels

When discussing cut-points in this social network, the focus is on the main component of the network, since four of the five smaller components only possess one obvious cut-point in their centre. Please see section 4.4 for the definition of cut-points.

There are only a few cut-points in this social network, indicated through orange circles in Figure 7.24. The major cut-points are DGNB1, HVAC1, PW2 and CM2. While DGNB1, HVAC1 and PW2 obviously function as an interface towards their immediate work team, CM2 interlinks with actors from various companies. This outcome was expected as CM2 is the project manager in charge. DGNB1 is the sustainability assessor, which explains his/her network position. However, it is interesting that apart from CM3, DGNB1 is only connected to professionals. This could indicate that he/she is not very approachable for operatives and supervisors. This aspect is similar to case study Germany1 but contrary to UK2. Thus there seems to be a difference between a sustainability assessor and manager in terms of enhancing the KT on sustainable construction.

It is rather difficult to make a statement regarding the hierarchy levels in this social network, as there is no data on the job level for nine nodes. Moreover the network thus the knowledge transfer is very distributed with seven components.

7.3.3.4. Relationship between Network Density and Tie Characteristics and Tie Contents

The network density is 0.0559 with a standard deviation of 0.4254. This value indicates a mean strength of all possible ties of 0.05, i.e. 5% of all possible ties are present in this network (Hanneman and Riddle, 2005). As discussed in Chapter 4 the maximum value would be 1.0, i.e. 100% of all possible ties being present. 0.05 is a very low value, implying that this network is sparse rather than cohesive. The standard deviation is larger than the mean, which indicates a great variation in the strength of ties.

As argued in the previous case studies, the strength of a tie defines the type of knowledge that is transferred through it, as weak ties seem to limit the exchange of tacit knowledge (Fernie *et al.*, 2003). Hence it is vital to explore the nature of transferred knowledge further. The three different categories of the content and type of knowledge on sustainable construction, including both tacit and explicit knowledge, were defined in section 5.3.1. Table 7.31 provides an overview of the frequencies of the various tie contents of the 58 KTs on which research participants provided data.

Table 7.31: Tie Contents of Knowledge Transfers in Case Study Germany2

Tie Content	**Knowledge Type**	**Frequency Count**	**Valid Percentage**
All: Materials, Technologies and Techniques	Explicit and tacit	19	32.77%
Materials and Techniques	Explicit and tacit	7	12.07%
Materials	Explicit	6	10.34%
Techniques	Tacit	6	10.34%
Materials and Technologies	Explicit and tacit	2	3.45%
Technologies	Explicit and tacit	2	3.45%
Technologies and Techniques	Explicit and tacit	0	0%
No data on tie content	-	16	27.58%

As indicated in Table 7.31, the subjects discussed in this case study were generally very varied. The most frequently mentioned subject by far is a combination of all three subject areas (materials, technologies and techniques) with 32.77%. This finding was partially expected, as it was argued in section 5.3.1 that new sustainable materials and technologies might need adjusted or new techniques for their installation. As a result many questions might evolve around new materials/ technologies and the techniques to apply these. Hence this finding supports this argument.

The discussed subject areas give further indications to the knowledge types transferred and thus can be linked back to the tie characteristics and the network density. It was argued that the knowledge of materials and technologies is in the main explicit. However, the knowledge of techniques was defined in section 5.3.1 as fully tacit. Hence any combination with techniques represents a combination of tacit and explicit knowledge. Therefore tacit knowledge was part of in total 55.18% of the transferred knowledge through this rather sparse network. As a result the relatively large amount of transferred tacit knowledge is a significant finding and similar to the previous case studies. It could indicate strong ties in this rather sparse network. Literature (Augier, Vendelø, 1999; Granovetter, 1973; Fernie *et al.;* 2003) argues that tacit knowledge is best transferred through strong ties, as discussed in section 4.4.2. Strong ties can be defined by long, close relationships with high trust (Granovetter, 1973). Therefore the results on the knowledge sources in section 7.3.3.7 provide further insights into this matter.

7.3.3.5. Relationship between Tie Contents and the Actor Attribute Job Level

In order to determine whether knowledge on certain subject areas is more in demand by a particular workforce group, cross tabulation was carried out between tie contents and job level. The results are presented in Table 7.32 and show the job level of the person who asked for advice on sustainable construction.

Table 7.32: Tie Contents of Knowledge Transfers linked with Actor Attribute Job Level in Case Study Germany2

	No data on Tie Content	**Materials**	**Technologies**	**Techniques**	**Materials and Technologies**	**Materials and Techniques**	**Techniques and Technologies**	**All three subject areas**	**Total**
Apprentice	0%	0%	0%	100%	0%	0%	0%	0%	**100%**
Operative	0%	0%	0%	0%	0%	44.45%	0%	55.55%	**100%**
Supervisor	0%	16.66%	0%	16.66%	16.66%	0%	0%	50%	**100%**
Professional	0%	20%	10%	15%	5%	15%	0%	35%	**100%**

Table 7.32 indicates that the most discussed subjects for each job level were:

- Apprentices → Techniques
- Operatives → All three subjects; Materials and techniques
- Operatives' Supervisors → All three subjects
- Professionals → All three subjects; Materials

This finding shows that the previously most discussed subject area (a combination of all three subject areas) was discussed by all three main job levels involved, i.e. operatives, supervisors and professionals. This indicates that they are not only concerned with the 'what' in terms of new sustainable building materials or technologies, but also with the 'know-how', i.e. their correct installation, to achieve a good quality sustainable built result.

Nonetheless Table 7.32 also shows a slight difference depending on the job level. Professionals are also concerned about materials, operatives about a combination of materials and techniques, and apprentices about techniques only. This finding shows clearly that the 'job level' does have a strong influence on the tie contents. As argued in section 7.3.2.3 the actor attribute 'job level' already had an influence on the awareness and training of the practitioners. As a result this finding further supports the claim of the strong influence of the actor attribute 'job level' on various aspects of the KT on sustainable construction.

7.3.3.6. Relationships between Centrality Measures and the Actor Attributes Job Level and Age

This section explores the centrality measures of the nodes in this knowledge transfer network. Figure 7.25 illustrates the same network map as Figure 7.24, but with a focus on the node sizes. The node sizes represent the degree centrality of the actors, i.e. the larger the node the more central the actor in relation to KT on sustainable construction.

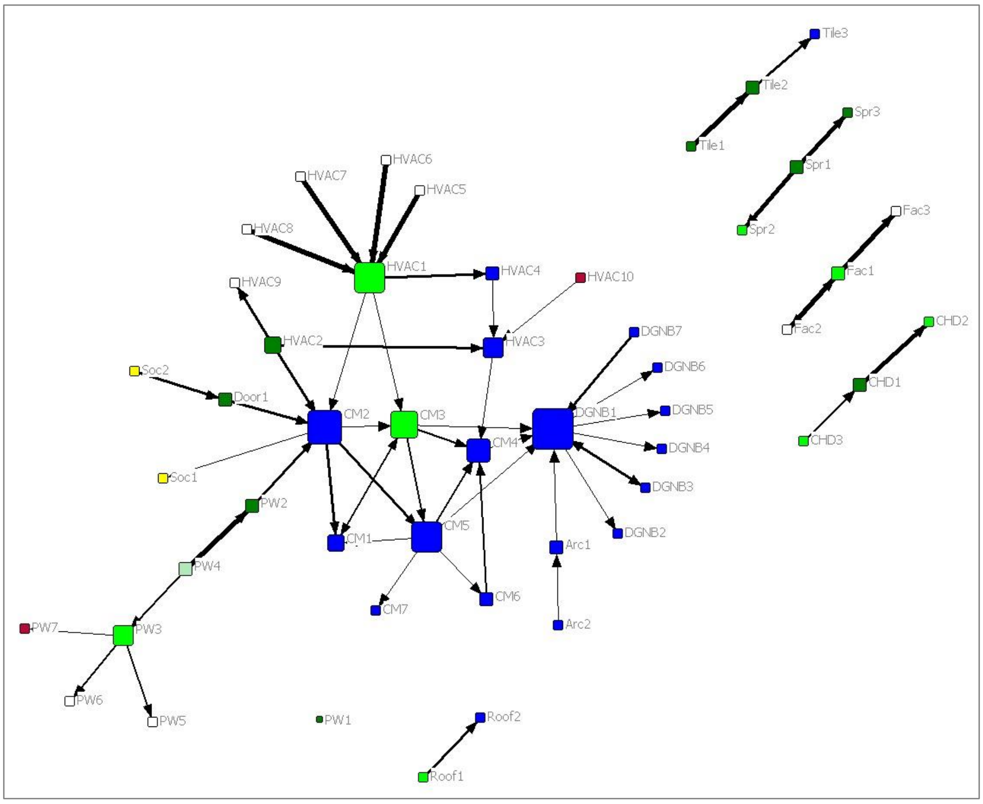


Figure 7.25: Knowledge Transfer Network of Case Study Germany2 – Degree Centrality

In order to support Figure 7.25, Table 7.33 presents the five most central actors for in-degree and out-degree centrality and their respective other value.

Table 7.33: Centrality Measures in Case Study Germany2

Actor	In-Degree	Actor	Out-Degree
HVAC1	20	Fac1	10
CM2	10	HVAC2	9
DGNB1	10	CM2	8
CM4	7	Spr1	8
CM1	6	CM3	7
Fac1	5	DGNB1	6
CM3	3	HVAC1	5
HVAC2	0	CM4	1
Spr1	0	CM1	1

It was vital to investigate whether the in- and out-degree values are linked with the actor attributes job level and age, as shown below.

Perceived experts:

- HVAC1, supervisor at the HVAC company, age group: 35-44
- CM2, construction project manager in charge, age group: 25-34
- DGNB1, sustainability assessor of this project, age group: 35-44
- CM4, professional at the construction management company, age group: 45-54
- CM1, professional at the construction management company, age group: 55-64

Knowledge consumers or brokers:

- Fac1, supervisor at the façade company, age group: 45-54
- HVAC2, operative at the HVAC company, age group: 45-54
- CM2, construction project manager in charge, age group: 25-34
- Spr1, operative at the sprinkler company, age group: 25-34
- CM3, professional at the construction management company, age group: 35-44

First of all there is clearly no link between age and being perceived as an expert on sustainable construction or a knowledge consumer, as there are actors from different age groups in both categories.

HVAC1, the supervisor at the HVAC company, is perceived by far to be an expert on sustainable construction. He/she is aware of the sustainability aim of the project, but did not receive any specialised training. HVAC1 elaborates on this further by stating that '*there is no time alongside the job to undergo further training'*. Moreover he/she stated that '*I gained my knowledge on sustainable construction through learning by doing'*. Nonetheless it is striking that HVAC1 is unsure whether they use sustainable materials or technologies. When examining his/her KTs in detail, these are mostly on problems encountered during installation and work progress, i.e. techniques. Although HVAC1 has an in-degree centrality value that is double of CM2, Figure 7.25 shows that he/she is only transferring knowledge towards the immediate work team, while receiving knowledge from the construction management company.

It could have been assumed that the project manager in charge, CM2, is regarded as a general expert not only on sustainable construction, but as a person to contact with any overall queries. Nonetheless he/she had no special training on sustainable construction. However, Table 7.33 indicates that CM2 is not only giving, but also receiving a lot of knowledge on sustainable construction. When examining the kind of transferred knowledge in more detail, it shows that he/she seems to be an expert on all three subject areas, but a knowledge consumer on techniques only. Yet this could indicate that CM2 is a gatekeeper.

DGNB1 is the sustainability assessor on this project and received training as a DGNB auditor and LEED AP. He/she seems to be perceived as an expert on sustainable construction in this project mainly by professionals and not by operatives or supervisors, as illustrated in Figure 7.25. The knowledge he/she shares with the other project participants is on various combinations of all three subject areas, but particularly in order to fulfil the requirements set by the DGNB.

As illustrated in Figure 7.25, DGNB1 has the highest average degree centrality with respect to the KT on sustainable construction. This is in line with the findings of a other case studies where the sustainability assessor or manager takes over the central position next to the architect or the project manager. As previously pointed out this finding is an indication that sustainability issues are changing the way construction industry conducts its business (Rohrbacher, 2001). In terms of KT on sustainable construction this could suggest employing a sustainability manager or assessor in order to have a contact person for issues related to sustainable construction (Thomson *et al.,* 2010).

CM4 and CM1 are professionals from the construction management company, who are both aware of the sustainability aim of this project, but did not receive any special training. The advice CM4 gives is mostly on materials and techniques, while CM1 gives advice on all three subject areas.

Fac1, the supervisor at the façade company, is clearly a knowledge consumer with an out-degree centrality of 10. Nevertheless he/she only requests knowledge inside the small network component, i.e. the façade company, which could be due to competitive behaviour (Sharkie, 2003). HVAC2, an operative from the HVAC company was not aware of the sustainability aim, but asked many questions on various combinations of all three subject areas. The same is the case for Spr1, an operative at the sprinkler company. This result supports the previous findings that the unawareness of sustainability is lager within the operatives.

CM2 has a high in- and out-degree centrality. This could indicate that CM2 is a gatekeeper, as described in Chapter 4 or he/she could be an expert in one area and a consumer in another. The following calculations on betweenness centrality explore this issue further. Gatekeepers are important in this study as they pass on the knowledge on sustainable construction and thus enhance KT on sustainable construction. The results are summarised in Table 7.34.

Table 7.34: Betweenness Measures in Case Study Germany2

Actor	Betweenness
CM2	287
DGNB1	235
PW2	145
HVAC1	143.83
CM3	128.17

Table 7.34 indicates that the main knowledge brokers in this social network are:

- CM2, construction project manager in charge
- DGNB1, sustainability assessor of this project
- PW2, operative at the plasterworks company
- HVAC1, supervisor at the HVAC company
- CM3, professional of the construction management company

Four of these five actors also had high degree centrality values. Thus this result confirms the earlier indication that CM2, CM3, DGNB1 and HVAC1 are gatekeepers. CM2 and DGNB1 have a betweenness value which is nearly double than the one of the other actors. This can be explained with their job roles as project manager in charge and sustainability assessor.

In summary the various centrality calculations proved a clear connection between the actor attribute ‘job level’ and actor centrality. Experts on sustainable construction seem to be professionals and supervisors, whereas knowledge consumers are more likely to be found within the operatives. The same is the case for the awareness of sustainability. The two most important knowledge brokers on sustainable construction knowledge were, as expected, identified as the project manager in charge and the sustainability assessor.

7.3.3.7. Knowledge Sources

This section explores the knowledge sources further, i.e. their role and what kind of relationship exists between the knowledge source and receiver, and why this person was chosen to ask for advice on sustainable construction. Please see sections 3.4.1 and 5.3.1 for the discussion on knowledge repositories and sources. The results were analysed with content analysis and summarised in Table 7.35. In total the participants provided this information for 57 knowledge transfers, thus the number in the right hand column is the count.

Table 7.35: Knowledge Sources in Case Study Germany2

Coding	Count
Colleague (on this project)	28
Supervisor / Manager	14
Colleague (from another company)	7
Sustainability assessor	4
Supply chain	2
Colleague (on another sustainable project)	1
Social contact	1
Total	**57**

Table 7.35 indicates that the most common knowledge source with a count of 28 was a colleague on this project, and by far more frequently consulted than a manager or supervisor (14). Indicating the knowledge source also indicates to a certain extent the tie content trust, as by asking for advice the actor admits being less knowledgeable in the subject area (Borgatti, Cross, 2003). Trust does affect KT as argued in section 3.4.1.3. Hence it might not be a surprise that colleagues are chosen over managers and supervisors, as there might be more trust based relations amongst them, than with someone from a superior job level. Therefore the results confirm literature on this subject. Moreover, as argued in the previous case studies, colleagues working on the same project together might have developed a so-called ‘transactive memory’ (Wegner et al., 1991), i.e. they know ‘who knows what’ (Berends, 2005). Please see section 3.4.1.2 for more details on this subject. Therefore the results on the choice of the knowledge source confirm the assertion from section 7.3.3.4 that the majority of the ties are relatively strong and thus facilitate the transfer of the large amount of tacit knowledge, in line with literature (Augier, Vendelø, 1999; Granovetter, 1973). Nonetheless, the results also show that these strong ties exist in a sparse network, similar to the two UK case studies. This finding is remarkable, as it shows that tacit knowledge can be transferred through a sparse network consisting of strong ties. Therefore this

questions existing literature and indicates a need for more research on the relationship of network density, tie strength and tacit KT.

Furthermore only seven out of 57 knowledge sources were colleagues from other involved companies, whereas most of these were actually the project manager in charge. Thus the findings presented in Table 7.35 do indeed confirm literature on the so-called silo-based structure of the industry (WBCSD, 2008; Kurul *et al.,* 2011), at least for this case study.

In addition it was further examined, whether the previously identified perceived experts and consumers differ in their knowledge source choice. The following list shows who they prefer to ask.

Perceived experts:

- HVAC1 supervisor
- CM2 colleague, father
- DGNB1 colleague, manager
- CM4 sustainability assessor
- CM1 does not ask anyone

Knowledge consumers or brokers:

- Fac1 supervisor, colleague
- HVAC2 supervisor, colleague
- CM2 colleague, father
- Spr1 supervisor, colleague
- CM3 colleague

The findings on this issue concord with the main outcome, as colleagues are the preferred knowledge source followed by supervisors. Nonetheless the order above shows that knowledge consumers ask their supervisors first, while experts prefer their colleagues. This could be due to the job levels of the consumers, i.e. operatives and experts, i.e. professionals.

7.3.3.8. Relationships between Knowledge Transfer Methods and the Actor Attributes Age, Job Level and Actor Centrality

The methods first used in order to seek knowledge and secondly in order to receive this required knowledge were investigated. The respondents filled in the methods used for each KT, and were also given the opportunity to add methods, if they used others. However, no research participant in this case study added any method, whereas most of the offered methods have been used. This might suggest that all the important methods were covered in the data collection tools. Figure 7.26 depicts the findings on this issue.

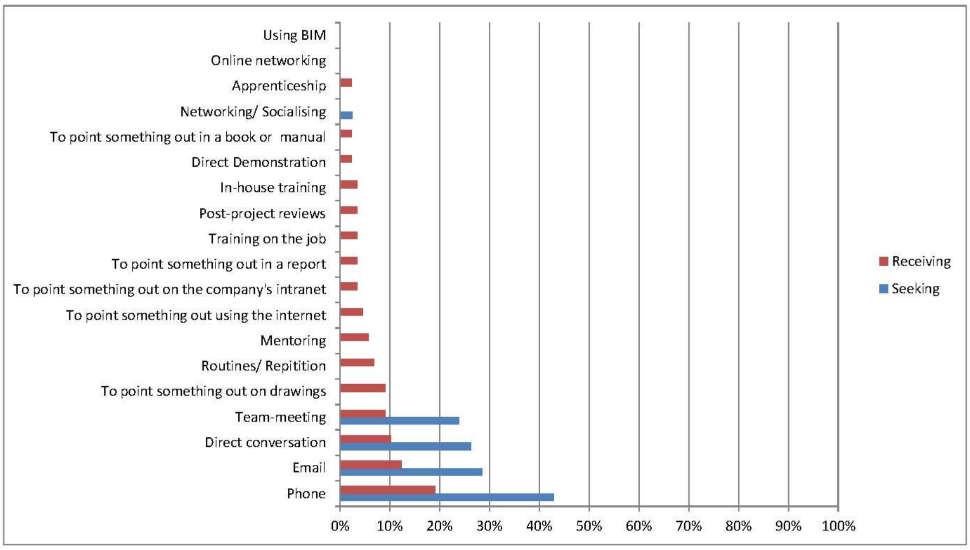


Figure 7.26: Knowledge Transfer Methods when seeking and receiving Knowledge in Case Study Germany2

Figure 7.26 shows that the participants sought knowledge on sustainable construction mainly by using phone, email, direct conversations and team meetings at a similar level. A very small percentage of knowledge was sought through socialising.

Most of the knowledge given was transferred using the same methods, i.e. phone, email, direct conversation and team meetings.

The eight most used methods to receive knowledge on sustainable construction in this case study in order of frequency were:

- Phone
- Email
- Direct conversations
- Team meetings
- To point something out on a drawing
- Routine/ repetition
- Mentoring
- To point something out on the internet

Most of these methods are, according to literature (Haldin-Herrgard, 2000; Egbu, 2004) used to transfer rather tacit knowledge. As a result the choice of these KT methods gives further indications of the tie contents. As discussed in section 7.3.3.4, tacit knowledge was part of 55.18% of all the knowledge transfers that occurred. Thus this selection of KT methods provides further evidence of the transfer of tacit knowledge through this sparse network.

All methods were used to transfer knowledge on sustainable construction apart from 'BIM' and 'online networking'. This is supported by one respondent's remark that he/she had never heard of BIM before.

The intranet is ranked as the 9th most used KT method which can be explained by the analysis of the qualitative data. One respondent stated that '*we do have an intranet, but do not use it.*' Another research participant supported this point of view by putting forward that *'our intranet functions as a security copy of our data base. We copy everything there until it is full, then we delete it and start over again. No one looks at it.'* These perceptions are similar to the previous case studies. There seems to be a trend in the results that intranet is problematic as a KM tool.

It is vital to investigate the relationships, if any, between the various chosen KT methods and actor attributes, such as 'age group', 'job level' and 'actor centrality'. Thus the following figures present the cross tabulation of these. The figures only focus on the eight most frequently used methods which were identified previously.

Figure 7.27 illustrates the cross tabulation results between 'age group' and the chosen KT methods.

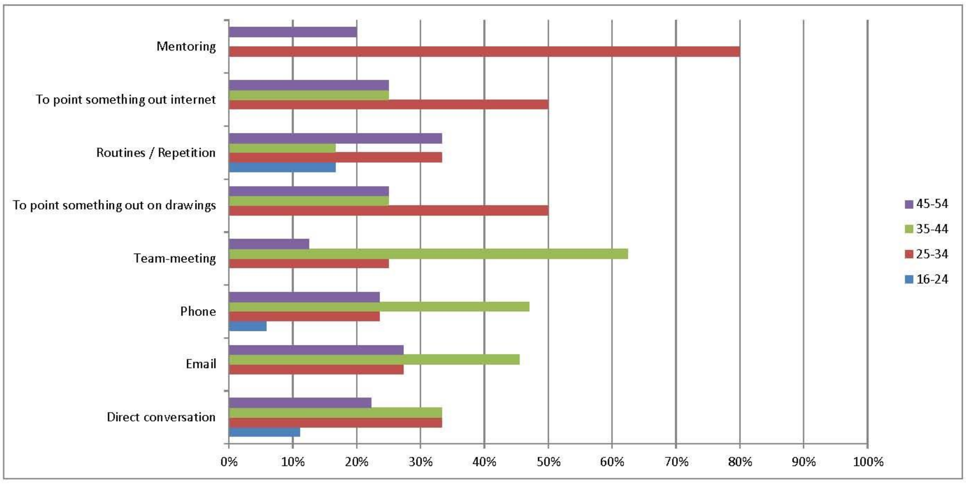


Figure 7.27: Knowledge Transfer Methods Cross Tabulation with Age Groups in Case Study Germany2

As presented in Figure 7.27, there does seem to be a slight difference in the methods chosen to transfer knowledge on sustainable construction depending on the age group. The youngest age group, i.e. 16-24 only used three out of these eight methods. This might suggest that with increasing work experience, employees learn how to transfer knowledge through a larger variety of methods. Moreover mentoring is only used by the age groups 25-34 and 45-54. This clearly shows that the 45-54 group are mentors to the 25-34 year old participants. Thus these findings suggest a link between the actor attribute age, and therefore experience, and the KT methods which were used. As argued in the previous case studies, age differences of participants in a KT can enhance or inhibit the it (Riege, 2005). The findings show that this could be due to e.g. preferring to use different methods to transfer knowledge.

Figure 7.28 presents the cross tabulation results between job level and the chosen methods to transfer knowledge.

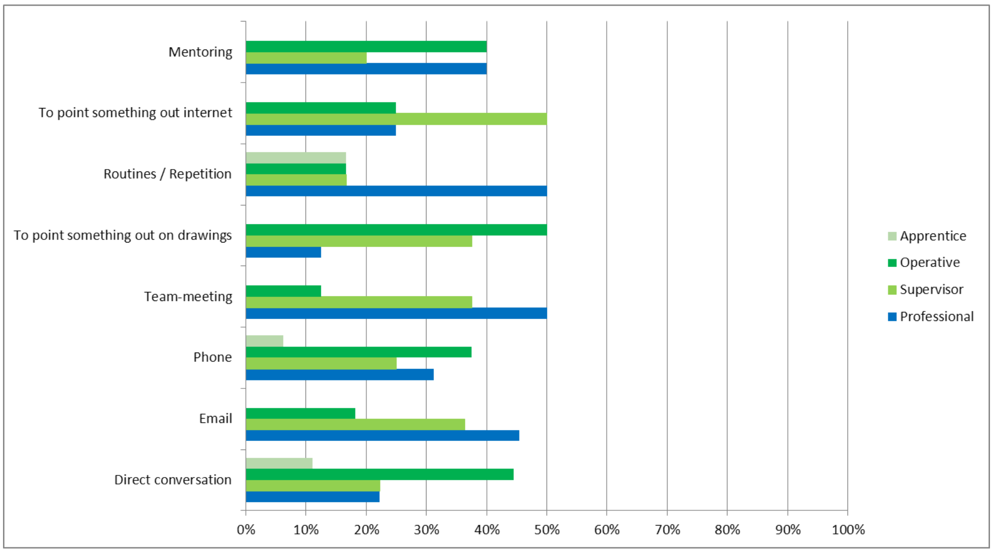


Figure 7.28: Knowledge Transfer Methods Cross Tabulation with Job Level in Case Study Germany2

As indicated in Figure 7.28, at this case study there seems to be no remarkable difference in the KT methods used by the various construction workforce members according to their job level, apart from the apprentice who only used three methods. This is in line with the previous figure on age groups as the apprentice is within the youngest age group.

In the previous section 7.3.3.5 the following five actors were identified as perceived experts on sustainable construction with the highest in-degree centrality. It was considered vital to examine their choice of KT methods in more detail.

- HVAC1, supervisor, 35-44 → team meeting, direct conversation
- CM2, professional, 25-34 → team meeting, demonstration, drawings
- DGNB1, professional, 35-44 → team meeting, phone, email
- CM4, professional, 45-54 → email, phone
- CM1, professional, 55-64 → not data

This shows that more central actors prefer similar KT methods. Moreover their choice of KT methods is according to their job level, i.e. in line with the results for the overall job levels presented in Figure 7.28. As a result this leads to the assumption that the link between KT methods and 'job level' seems to be stronger that the one with actor centrality.

7.3.3.9. Duration of Knowledge Transfer

Table 7.36 illustrates the results on the duration of the KTs in this case study.

Table 7.36: Duration of Knowledge Transfers in Case Study Germany2

Time in Minutes	Count	Percentage
5	8	13.79%
10	21	36.20%
15	5	8.62%
20	9	15.52%
30	4	6.89%
60	2	3.45%
No data	9	15.51%
Total	**58**	**100%**

The results for this case study show that most KTs take about 10 minutes (36.2%), while most others are up to 20 minutes. Only one respondent indicated two KTs of 60 minutes. This aspect is vital as construction projects are usually under a certain time pressure. Various studies have indicated that time constraints are a main reason for KTs not to occur (Hansen, 2002; Riege, 2005; Lu, Sexton, 2007). However, this result shows that it only takes on average about ten minutes to answer questions on sustainable construction. Hence this finding suggests that this rather small amount of time might be worthwhile to consider, if it leads to an overall better built result.

7.3.4. Conclusion

This section presented the findings of the second German case study. It began by giving a brief overview of the actor attributes of the research participants. The section then investigated to what extent the actor attributes and social network characteristics relate to each other and influenced the KT on sustainable construction in this case study.

Table 7.37: General Factors and Social Network Characteristics influencing KT on sustainable Construction in Case Study Germany2

	Awareness	Perceived Use of sustainable Material/ Technology	Training Received	Perceived Training Need	KT Methods	KT Source	Network Density	Job Level	Age
Age	x	x	x	x	√	x	n/a	n/a	n/a
Gender	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Nationality	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Education	Linked to job level								
Job level	√	√	x	x	√	√	n/a	n/a	n/a
Tie Contents	n/a	n/a	n/a	n/a	√	√	√	√	n/a
Actor Centrality	√	NP	x	x	x	√	n/a	√	x
Awareness	n/a	NP	n/a	n/a	n/a	√	n/a	√	x

√ - linked; x – not linked; NP – link not prominent enough; n/a – not applicable/ investigated

In summary the analysis carried out in this case study seems to suggest that a number of factors may broadly influence each other and KT on sustainable construction. Table 7.37 provides a summary of the findings, which will be explained in the succeeding paragraphs.

In regards to the so-called general influencing factors, such as gender and nationality, no remarkable results have been detected due to the nature of the sample, i.e. participants were mostly male and German. However, the term nationality might not fully reflect the cultural backgrounds of the respondents, as previously stated in section 3.4.1.1. Moreover the finding in section 7.3.2.2 confirmed that education defines job level later in life, hence these two actor attributes are linked. As a result succeeding analyses were conducted for job level only, but represent the variable educational background as well. The age group of the research participants was observed to only influence the choice of KT methods, as the older the actor the more methods he/she tended to use.

The actor attribute job level has had the most influence on other variables in this case study. Thus the job level influenced the awareness of sustainability, with operatives having a lower level of awareness. Here 23.8% of the respondents were not aware of the sustainability aim and were only operatives and one apprentice. It is interesting that 42.9% did not know whether they used sustainable materials/technologies. These respondents were only out of the construction workforce as well. This confirms the lower level awareness of operatives and their supervisors and suggests better informing and training them in order to raise their awareness. Additionally whether an actor is perceived as a knowledge source also appears to depend on the job level, with more professionals and supervisors being knowledge sources. Moreover the findings suggest a relationship between tie contents and job levels, as knowledge on certain subject areas was required more frequently by certain job levels. These results are similar to the UK1 case study, which has a comparable sample structure. Hence this suggests providing a knowledge flow that is more target-orientated to job levels.

The majority of respondents in this case study (90.5%) did not receive any specialised training on sustainable construction and they are wide-spread throughout the various job levels. Hence no link with job levels was detected. A wide range of answers to the question whether such training is actually required, shows a general lack of agreement as to the necessity of such training.

Regarding the social network characteristics, similar to the other case studies, the network density was found to be relatively low with a value of 0.05. This shows a sparse network resulting from not much KT on sustainable construction. However, tacit and explicit knowledge were transferred through this rather sparse network. In fact tacit knowledge was part of 55.18% of all KTs. In addition the link between tie contents and KT methods asserted in the literature was confirmed as the most frequently used KT methods prove the transfer of much tacit knowledge. As discussed in section 4.4.1 and 4.4.2, Granovetter (1973) and Reagans and McEvily (2003) argue that the tie characteristic, i.e. strength or weakness, determine the type of knowledge that is transferred. The choice of knowledge sources confirmed strong ties. Therefore this finding proves that it might be a sparse network but with strong ties, facilitating the transfer of large amounts of tacit knowledge, similar to the UK case studies. This is already the third case study with similar results on this matter. Hence this suggests more research linking network density, tie strength and tacit KT. This issue will also be observed in the last case study.

Centrality measures showed which actors are perceived as experts on sustainable construction by others, and which only consume knowledge. Here supervisors and professionals were perceived as experts, whereas operatives were mostly knowledge consumers. As a result there seems to be a link between actor centrality and job level, as expected. Additionally actors with a high in-degree centrality i.e. perceived experts showed more awareness of sustainable construction, although they did not all receive special training or felt the need for such training. Hence no link between centrality and training was detected. The main implications of this are to improve training on sustainable construction for supervisors, as operatives seem to largely depend on them.

The betweenness centrality calculations identified the two main gatekeepers of this construction project as the sustainability assessor and the project manager in charge. The high degree and betweenness centrality values of the sustainability assessor might suggest, similar to the previous case studies, the need for a sustainability manager or assessor in addition to the architect or construction project manager to facilitate KT on sustainability issues in the project.

Additionally the relationship to these knowledge sources was examined. The most common knowledge source was by far a colleague in this project, followed by a manager or supervisor. Only seven out of 57 knowledge sources were colleagues from other involved companies, whereas most of these were actually the project manager in charge. Thus the silo-based structure of the industry, argued by literature was confirmed for this case study.

Apart from BIM and online networking, all methods of the KT methods box of the conceptual framework were used. ‘DGNB Auditor and Leed AP training’ was added by research participants. Moreover it was found that similar to other case studies there is a link between the choice of KT methods and the age of the actor. Nonetheless no link between KT methods and job level and actor centrality were observed.

The findings on the duration of the KTs show that most KTs only require up to 20 minutes (74.13%). Nevertheless this is the first case study where some KTs took even 60 minutes, though only a small percentage. This is in line with the previous case studies and suggests that this relatively small amount of time might be worthwhile if it improves the built outcome.

The next part of this chapter presents the findings of the third German case study.

Key for Case Study Germany2

indicates research participants

Trade	Code	Job Level	Code
Architect	Arc	Professional	Arc1
		Professional	Arc2
DGNB	DGNB	Professional	DGNB1
		Professional	DGNB2
		Professional	DGNB3
		Professional	DGNB4
		Professional	DGNB5
		Professional	DGNB6
		Professional	DGNB7
Construction/ Interior fittings - project manager	CM	Professional	CM1
		Professional	CM2
		Supervisor	CM3
		Professional	CM4
		Professional	CM5
		Professional	CM6
		Professional	CM7
Core Hole Drilling	CHD	Operative	CHD1
		Supervisor	CHD2
		Supervisor	CHD3
Plaster works/ painter	PW	Operative	PW1
		Operative	PW2
		Supervisor	PW3
		Apprentice	PW4
		n.a.	PW5
		n.a.	PW6
		Supply chain	PW7
Roofer	Roof	Supervisor	Roof1
		Professional	Roof2
Tiler	Tile	Operative	Tile1
		Operative	Tile2
		Professional	Tile3
HVAC	HVAC	Supervisor	HVAC1
		Operative	HVAC2
		Professional	HVAC3
		Professional	HVAC4
		n.a.	HVAC5
		n.a.	HVAC6
		n.a.	HVAC7
		n.a.	HVAC8
		n.a.	HVAC9
		Supply Chain	HVAC10
Façade	Fac	Supervisor	Fac1
		n.a.	Fac2
		n.a.	Fac3
Steeldoors	Door	Operative	Door1
Sprinkler	Spr	Operative	Spr1
		Supervisor	Spr2
		Operative	Spr3
Contacts outside the project	Soc	Father of CM2	Soc1
		Friend of Door1	Soc2

7.4. Case Study Germany 3 – North

7.4.1. Research Setting

The construction project was a prime office scheme located in the North of Germany. The project covers approximately 19,800 square metres and was carried out by a main contractor. Construction started in 2011, with project completion planned for 2014. The project received a gold DGNB pre-certificate. A total of 11 questionnaires were collected mainly in an on-site office.

The project attained the following scores in the six main criteria groups of the DGNB certificate, as presented in section 2.4.3.

Table 7.38: Sustainable Performance of Project Germany3

Categories	**Score**
Overall quality of the building	81.7%
Ecological Quality	79.7%
Economic Quality	75.5%
Sociocultural and functional quality	84.1%
Technical quality	81.9%
Quality of the process	94.3%
Quality of location	82.8%

7.4.2. Actor Attributes

This section outlines some of the respondents' so-called actor attributes and investigates their relationships, if any.

7.4.2.1. Age, Gender and Nationality

Figure 7.29 shows that the age range of the research participants in this case study was relatively diverse with 18.2% between 25 and 34, 35 and 44, and between 55 and 64. 45.5% of the participants were between 45 and 54, and none between 16-24. As illustrated in Figure 7.30 all respondents were male (100%). In addition practitioners from two different countries participated in this research, i.e. Germany (90.9%) and Austria (9.1%) (see Figure 7.31). As all participants were male and mostly German, no remarkable results were found in cross tabulations with these variables. The possible multi-cultural background of some respondents is not completely reflected by these results, as only data on the actual citizenship was collected. Therefore 'age group' was singled out of these variables for succeeding analyses.

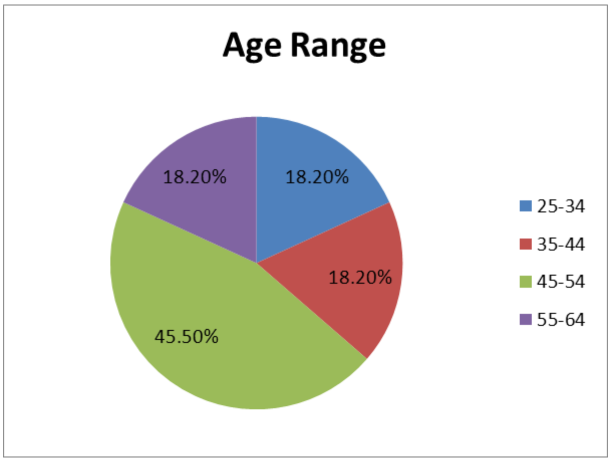


Figure 7.29: Age Range of Research Participants in Case Study Germany3

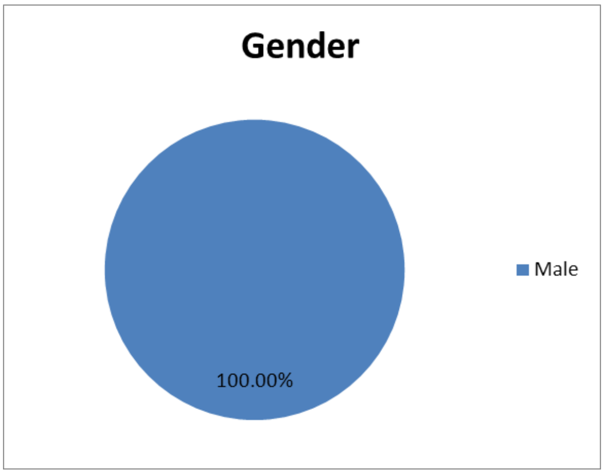


Figure 7.30: Gender of Research Participants in Case Study Germany3

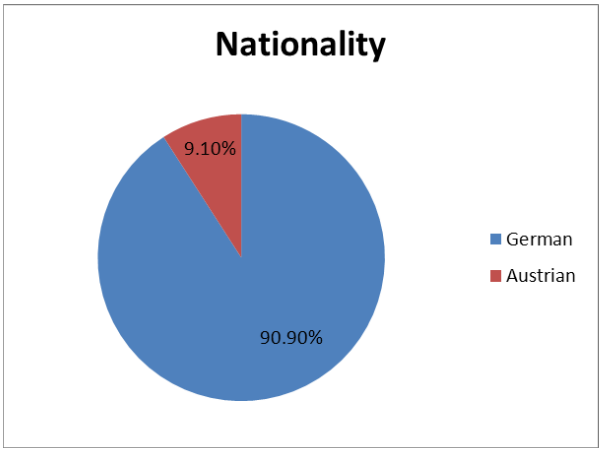


Figure 7.31: Nationality of Research Participants in Case Study Germany3

7.4.2.2. Educational Background and Job Levels

The educational background of the research participants is depicted in Figure 7.32. Of all research participants 54.5% had completed an apprenticeship and 45.5% held a Diplom. Please see section 7.2.2.2 for more details on the German degree system. Figure 7.33 illustrates that this case study included participants from three job levels, i.e. operatives (18.2%), operatives' supervisors (36.4%) and professionals (45.5%).

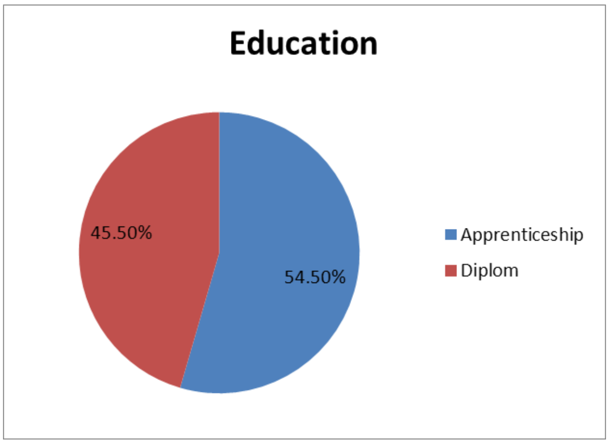


Figure 7.32: Educational Background of Research Participants in Case Study Germany3

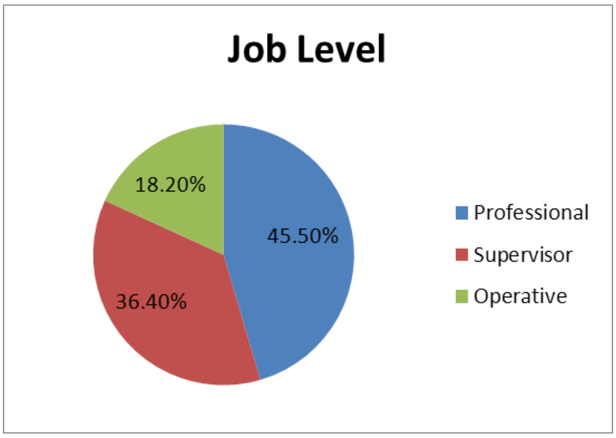


Figure 7.33: Job Level of Research Participants in Case Study Germany3

The cross tabulation shown in Table 7.39 confirms the strong relationship between 'educational background' and 'job level', as expected. As a result the succeeding analyses in this case study will equate 'educational background' with 'job level'. Hence the results of succeeding analyses with 'job level' stand for 'educational background' as well.

Table 7.39: Cross Tabulation between educational Background and Job Level in Case Study Germany3

	Job Level			**Total**
Educational Background	Professional	Supervisor	Operative	
Apprenticeship	0	4	2	6
Diplom	5	0	0	5
Total	5	4	2	11

7.4.2.3. Awareness of Sustainability

Figure 7.34 indicates that 90.9% of the respondents in this case study were aware that this construction project strived to achieve a DGNB certificate. This result is considered to be very high compared to the other case studies. One respondent explained the high awareness with a '*constant KT between the client, the technical planners and the construction companies.'*

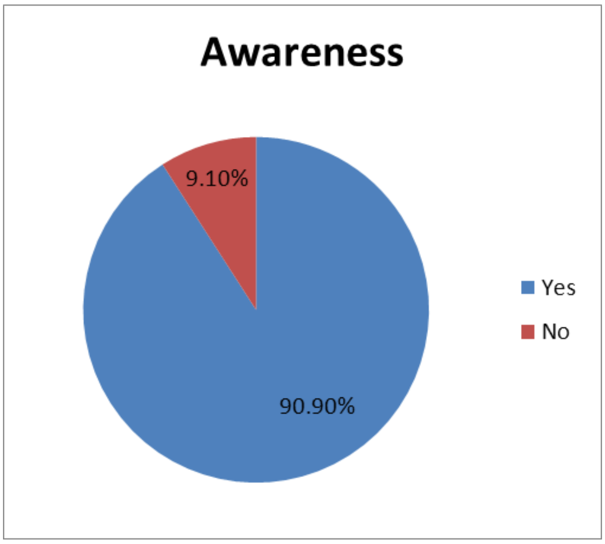


Figure 7.34: Awareness of Sustainability of Research Participants in Case Study Germany3

Since the level of awareness is so high in this case study it was not possible to find any prominent links with other variables, such as 'age group' or 'job level' when investigating these relationships further. This is similar to case study GE1 which had an awareness of 100%. The only respondent who was not aware was of the age group 54-65 and an operative.

7.4.2.4. Perceived Use of Sustainable Materials and Technologies

Figure 7.35 summarises the responses to the question whether the research participants were aware, if their companies use any sustainable material or technology. Here it is interesting that 81.8% of the answers were positive. This is the highest result of all case studies and can probably be explained with the high overall awareness of sustainability (90.9%).

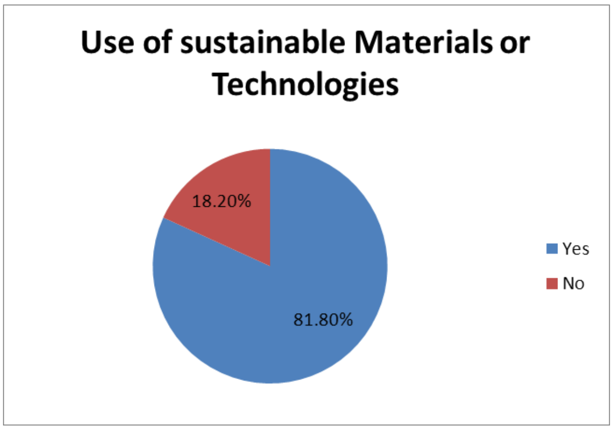


Figure 7.35: Perceived Use of sustainable Materials/ Technologies in Case Study Germany3

The cross tabulation in Table 7.40 shows that there is no relationship between the perceived use of sustainable materials and job level in this case study.

Table 7.40: Cross tabulation between perceived Use of sustainable Materials/ Technologies and Job Level in Case Study Germany3

	Perceived use of sustainable materials and technologies		Total
Job Level	**Yes**	**No**	
Professional	4	1	5
Operative	1	1	2
Supervisor	4	0	4
Total	9	2	11

The cross tabulation presented in Table 7.41 shows that there is also no link between the perceived use of sustainable materials and ‘age group’ in this case study.

Table 7.41: Cross Tabulation between perceived Use of sustainable Materials/ Technologies and Age in Case Study Germany3

	Perceived use of sustainable materials and technologies		Total
Age Groups	**Yes**	**No**	
25-34	2	0	2
35-44	2	0	2
45-54	4	1	5
55-64	1	1	2
Total	9	2	11

The respondents elaborated further on their use of sustainable materials and technologies which was analysed using content analysis, as explained in section 5.6.3. The results are summarised in Table 7.42. This data derives only from the respondents who elaborated further on this topic. The materials and technologies named by research participants are for the most part sustainable. This suggests that amongst those research participants who elaborated on this matter, there is a very high level of understanding and awareness about sustainable materials and technologies.

Table 7.42: Sustainable Materials/ Technologies as perceived by Research Participants in Case Study Germany3

Code	Count	Percentage
Formwork release oil has a 'Blauer Engel' symbol	1	20%
Stones and mortar	1	20%
Renewable energy	1	20%
Grey water recycling	1	20%
Pipes and cables	1	20%

Some participants made further statements on this issue. The building physician put forward that '*the energy efficiency, the user comfort and the economic efficiency have the greatest importance during the planning process.*' This is an extraordinary statement as it relates to all three pillars of sustainability described in Chapter 2, and not as so often in practice to only energy efficiency. The sustainability manager of the construction company mentioned that *'the materials and technologies used in this project were compared using a QM (Quality Management) system. Thereafter the client gives the approval for which materials and technologies to use.'* A supervisor stated that *'environment issues always play an important role during purchasing materials.'* However, one bricklayer elaborated further on why he/she is aware of using a sustainable material/ technology *'because it says so on the packaging.'* These statements are also breaking the job level hierarchy down in terms of the knowledge on why a sustainable material/ technology is being used, it is obvious that the operative is left out of the chain. Previous case studies suggested informing operatives more on the reasoning and importance of the use, as it is assumed that an enhanced KT most likely supports the improvement of the built outcome.

7.4.2.5. Received and Required Training on Sustainable Construction

Figure 7.36 shows the training which has been received on sustainable construction techniques, while Figure 7.37 presents the perceived requirement for such training.

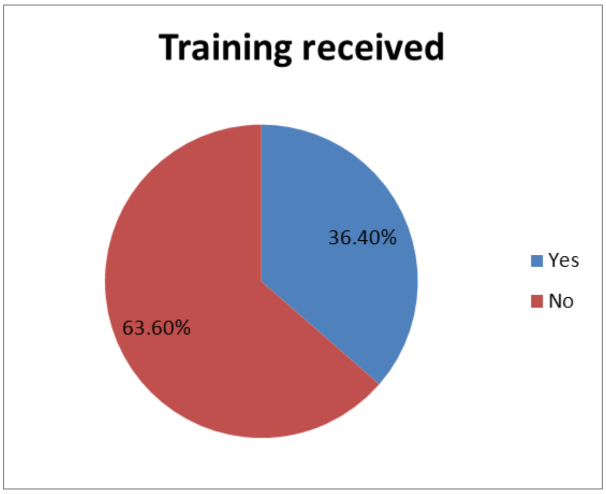


Figure 7.36: Training on sustainable Construction received by Research Participants in Case Study Germany3

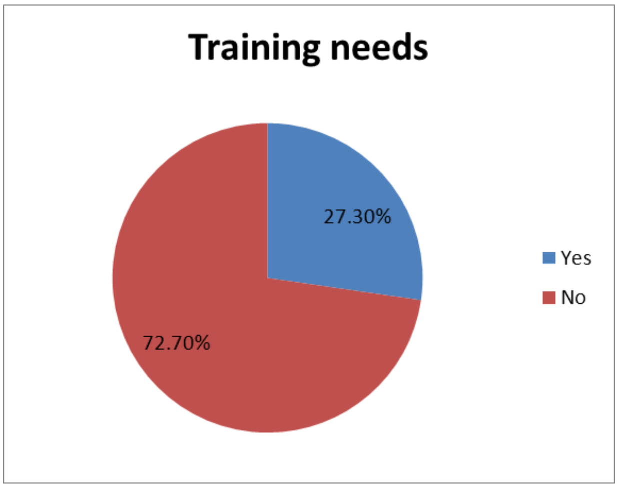


Figure 7.37: Perceived Requirement for Training on sustainable Construction by Research Participants in Case Study Germany3

Out of all respondents, 36.4% stated that they have had special training on sustainable construction and only 27.3% acknowledged the requirement of such specific skills. These results are relatively low compared to other case studies. Two respondents put forward that *'the sustainable materials used are very similar to conventional ones, thus do not require any special training.'* This statement was also observed in all five case studies. In addition two other research participants stated that '*there are certain guidelines, installation instructions and code of practice on how to install the sustainable materials and technologies which they follow.'* As a result these comments provide further explanations on why most participants in this case study did not consider special sustainability training as necessary.

It was vital to further investigate whether there are any links between 'training' and 'age group', and 'training' and 'job level'.

Table 7.43: Cross Tabulation between received Training and Age Group in Case Study Germany3

	Received training		**Total**
Age Group	Yes	No	
25-34	0	2	2
35-44	2	0	2
45-54	2	3	5
54-65	0	2	2
Total	4	7	11

Table 7.44: Cross Tabulation between Training Needs and Age Group in Case Study Germany3

	Perceived training needs		**Total**
Age Group	**Yes**	**No**	
25-34	0	2	2
35-44	1	1	2
45-54	2	3	5
54-65	0	2	2
Total	3	8	11

As depicted in Table 7.43 it is evident that the majority of research participants who did not receive any special training are within various age groups. Moreover 72.7% of the research participants did not consider such training necessary (see Figure 7.37) and were spread across the different age groups as well. Thus age does not influence training issues in this case study. When comparing the two tables it is even clear that except one, all participants gave the same reply to both questions. This one person did receive training but did not feel the need for more training.

Table 7.45: Cross Tabulation between Job Level and received Training in Case Study Germany3

	Received training		**Total**
Job Level	**Yes**	**No**	
Professional	3	2	5
Operative	0	2	2
Supervisor	1	3	4
Total	4	7	11

Table 7.46: Cross Tabulation between Job Level and Training Needs in Case Study Germany3

	Perceived training needs		**Total**
Job Level	Yes	No	
Professional	2	3	5
Operative	0	2	2
Supervisor	1	3	4
Total	3	8	11

The majority of respondents in this case study (63.6%) did not receive any specialised training on sustainable construction (Figure 7.36) and are wide-spread throughout the various job levels, as depicted in Table 7.45. Table 7.46 presents a wide range of answers in relation to the question whether such training is actually required. Hence no link with ‘job level’ was detected. Nonetheless, this shows a general lack of agreement as to the necessity of such training, similar to the other case studies.

In order to explore the issue of training and skills on sustainable construction further, the research participants were asked to elaborate further on the question what kind of training they received or why they had not received any. This information was analysed using content analysis, as presented in section 5.6.3. This data only derives from the respondents who elaborated further on this topic. The results are summarised in Table 7.47.

Table 7.47: Perceptions of sustainable Construction Training in Case Study Germany3

Code	Count	Percentage
No time for training	2	16.66%
DGNB Auditor	2	16.66%
In-house course	1	8.33%
Seminar on specific products by manufacturers	1	8.33%
No reason for training	1	8.33%
No training was offered	1	8.33%
'Hauptverband der Deutschen Bauindustrie'	1	8.33%
EnEV (German energy saving ordinance) energy consultant training	1	8.33%
Fire Safety	1	8.33%
First Aid	1	8.33%

Since at this case study the majority of respondents did not undergo any special training on sustainable construction the elaborations in Table 7.47 further illuminate this issue. Perhaps it is due to the fact that they have not had many opportunities to work on projects aiming for sustainability certificates to justify an investment in training. It could simply be that employers are expecting employees to learn on-the-job, particularly where activities involve substitution of materials which do not have a high degree of novelty. Time constraints are a constantly emerging issue when it comes to training and KT throughout all case studies. 'Fire safety' and 'first aid' are simply wrong answers and indicate that the respondents listed any training they ever received without differentiating whether it was actually on sustainability.

The remaining replies, do concern how participants received their knowledge on sustainable construction, and are therefore about KT methods. Hence they were particularly interesting in regards to testing the conceptual framework in practice.

- In-house course
- Seminar on specific products by manufacturers
- DGNB Auditor
- 'Hauptverband der Deutschen Bauindustrie'
- EnEV (German energy saving ordinance) energy consultant training

One of these five knowledge transfer methods above were already part of the conceptual framework presented in Chapter 5. Moreover, *DGNB Auditor* was already suggested to be added to the framework in the previous case study. Thus this recurrence confirms this suggestion. The same is the case for *seminar on specific products* by manufacturers which was already mentioned in case study

UK1. Moreover *EnEV energy consultant training* was mentioned and the *Hauptverband der Deutschen Bauindustrie* is a professional organisation of the German construction industry. Most likely this organisation was used in terms of professional networking.

The next section examines the social network characteristics, their relationships and to what extent they influenced KT on sustainable construction.

7.4.3. Social Network Characteristics

Figure 7.38 illustrates the knowledge transfer network of this case study. The colour coding and line weights used are in accordance with the description provided in section 5.6.4. Please also see the key at the end of this case study for clarification of the figures within this chapter.

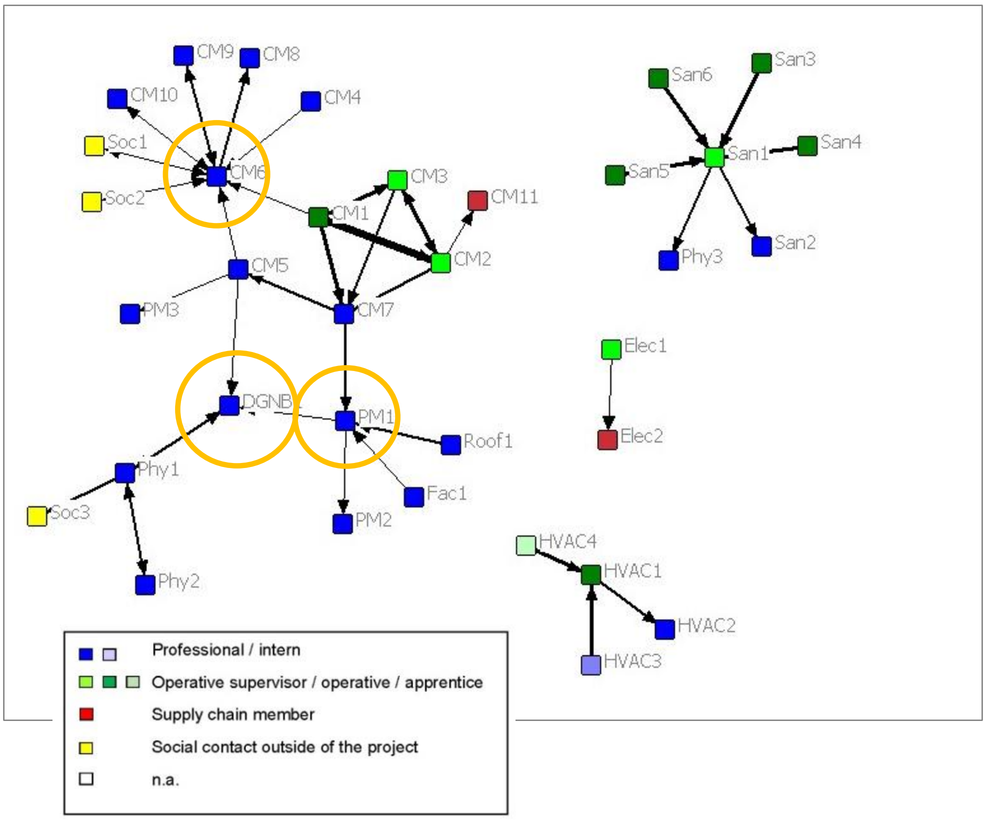


Figure 7.38: Knowledge Transfer Network of Case Study Germany3

7.4.3.1. Size of the Network

This network comprises of 35 nodes. As you can see in the fold-out key at the end of this case study, only 11 out of the 35 were research participants. The other 24 actors were named by them. Nevertheless, apart from the three social contacts, all 35 actors were involved in the same construction project. As stated in section 5.5.2.1 the network boundary was defined as all participants on one particular sustainable office construction project. The sampling which led to these 11 respondents is presented in section 5.4.2.

7.4.3.2. Network Structure

The network structure consists of one main component on the left hand side, and three smaller components on the right hand side of Figure 7.38. The main component includes the following companies: project management, sustainability assessor, construction management, roofer, façade and building physics. The three small components represent each one company, i.e. sanitation contractors, electrical contractors and HVAC contractors.

As for the sanitation contractors one could argue that their involvement with the other trades might not be as vital for the sustainable built outcome as for other companies. They do not require knowledge on sustainable construction from other project participants in order to fulfil their job, compared to for instance construction contractors. Therefore this could be the reason why they are not connected to the main component. Nevertheless the isolated network position of the electrical and HVAC contractors is unclear. Surely respondent behaviour is one reason for this network structure. Particularly for HVAC1, an operative being in such a central position within the smaller component. As shown on the fold-out key at the end of this case study these central actors (San1, Elec1, HVAC1) were research participants. Follow-up interviews could have provided better explanations of this issue, but were unfortunately not possible, as described in section 9.4 - Limitations.

This is the only case study with no isolate.

7.4.3.3. Cut-Points and Hierarchy Levels

Please see section 4.4 for the definition of cut-points. When discussing cut-points in this social network, the focus is on the main component of the network, since two of the three smaller components only possess one obvious cut-point in their centre. The third one is a dyad without a cut-point.

There are only a few cut-points in this social network, indicated with orange circles in Figure 7.38. The major cut-points are DGNB1, PM1 and CM6. While CM6 obviously functions as an interface towards his/her immediate work team, DGNB1 and PM1 interlink with actors from various companies. This outcome was expected as PM1 is the project manager in charge. Yet, CM6 is the sustainability manager of the construction management company. Though it seems that apart from CM1 he/she only gives advice to professionals of the construction management company. DGNB1 is the sustainability assessor, which explains his/her network position. However, DGNB1 does not possess many linkages to other actors. This is because he/she was not able to fill in the questionnaire due to time pressure. Hence the depicted links are only the ones indicated by other actors.

The KT on sustainable construction in this network is according to hierarchy levels. As indicated in Figure 7.38, operatives tend to ask supervisors, who in turn ask professionals for advice. The smaller component of sanitation contractors in the top right corner of Figure 7.38 illustrates this hierarchical knowledge flow very well.

7.4.3.4. Relationship between Network Density and Tie Characteristics and Tie Contents

The network density is 0.0899 with a standard deviation of 0.5880. This value indicates a mean strength of all possible ties of 0.08, i.e. 8% of all possible ties are present in this network (Hanneman and Riddle, 2005). As discussed in Chapter 4 the maximum value would be 1.0, i.e. 100% of all possible ties being present. 0.08 is a very low value, implying that this network is sparse rather than cohesive. Yet this is the case study with the highest density. The standard deviation is larger than the mean, which indicates a great variation in the strength of ties.

As previously stated there is a link between network density, tie characteristics and tie contents, which affects KT on sustainable construction. According to the literature a sparse network with weak ties is better for transferring explicit knowledge, as weak ties seem to limit the exchange of tacit knowledge (Fernie *et al.*, 2003). Hence it is vital to explore the nature of transferred knowledge further. The three different categories of content and type of knowledge on sustainable construction were defined in section 5.3.1. Table 7.48 provides an overview of the frequencies of the various tie contents of the 44 KTs on which the research participants provided data.

Table 7.48: Tie Contents of Knowledge Transfers in Case Study Germany3

Tie Content	Knowledge Type	Frequency Count	Valid Percentage
Materials	Explicit	12	27.27%
Techniques	Tacit	12	27.27%
All: Materials, Technologies and Techniques	Explicit and tacit	10	22.72%
Materials and Techniques	Explicit and tacit	5	11.36%
Technologies and Techniques	Explicit and tacit	2	4.54%
Technologies	Explicit and tacit	0	0%
Materials and Technologies	Explicit and tacit	0	0%
No data on tie content	-	3	6.81%

As indicated in Table 7.48, the subjects discussed in this case study were less varied compared to the other case studies. The most frequently mentioned subject areas were materials and techniques, with each 27.27%. This finding was partially expected, as it was argued in section 5.3.1 that new sustainable materials might need adjusted or new techniques for their installation. As a result many questions might evolve around new materials and the techniques to apply these. Hence this finding supports this argument. Nonetheless it was rather expected to find a combination of these two subject areas as in the previous case studies, than the two subject areas separately. This is the first case study where this phenomenon appears. A combination of all three subject areas is the third most discussed theme with 22.72%. Furthermore materials and technologies, and technologies were not discussed at all in this case study. This could be due to the early stage the construction stage was in at the time of data collection. That is the participants were occupied with the building structure and not the installation of sustainable technologies yet.

The importance of ‘materials’ can be explained through several statements. One respondent put forward that *‘there are so many different sustainability labels for materials that it is not clear what they all mean.’* Another participant agrees with this, by saying *‘in the long term it would be better if only materials are going to be used that are DGNB approved.’* This goes along with the statement of a third respondent who suggested a DGNB label for materials. These discussions are similar to the first German case study, where the sustainability levels of materials were a major issue.

The discussed subject areas give further indications to the knowledge types transferred and thus can be linked back to the tie characteristics and the network density. In the main, the knowledge of materials and technologies is explicit. However, the knowledge of techniques was defined in section 5.3.1 as fully tacit. Hence any combination with techniques represents a combination of tacit and explicit knowledge. Therefore tacit knowledge was part of in total 65.89% of the transferred knowledge through this rather sparse network. As a result the relatively large amount of transferred tacit knowledge is a remarkable finding and similar to the other case studies. It was argued in the previous case studies that strong ties might facilitate the transfer of this large amount of tacit knowledge, in line with literature (Granovetter, 1973; Augier, Vendelø, 1999). The discussion on knowledge sources in section 7.4.3.7 will explore this issue further.

7.4.3.5. Relationship between Tie Contents and the Actor Attribute Job Level

In order to determine whether knowledge on certain subject areas is more in demand by a particular workforce group, cross tabulation was carried out between tie contents and job level. The results are presented in Table 7.49 and show the job level of the person who asked for advice on sustainable construction.

Table 7.49: Tie Contents of Knowledge Transfers linked with Actor Attribute Job Level in Case Study Germany3

	No data on Tie Content	Materials	Technologies	Techniques	Materials and Technologies	Materials and Techniques	Techniques and Technologies	All three subject areas	Total
Apprentice	0%	0%	0%	100%	0%	0%	0%	0%	**100%**
Operative	0%	0%	0%	50%	0%	40%	0%	10%	**100%**
Supervisor	0%	50%	0%	40%	0%	10%	0%	0%	**100%**
Professional	13.63%	36.36%	0%	9.09%	0%	0%	9.09%	31.81%	**100%**

Table 7.49 indicates that the most discussed subjects for each job level were:

- Apprentices → Techniques
- Operatives → Techniques; Materials and techniques
- Operatives' Supervisors → Materials; techniques
- Professionals combined → Materials; All three subject areas

This finding shows that the previously identified most discussed subject areas materials and techniques are discussed by all three main job levels involved, i.e. operatives, supervisors and professionals. Nonetheless while supervisors and professionals discuss these two subject areas separately, operatives also link them as well. This is most likely because they need to link these areas in terms of installing the materials. Moreover apprentices are only concerned about techniques. Thus the findings in Table 7.49 show a link between the actor attribute 'job level' and tie contents.

7.4.3.6. Relationships between Centrality Measures and the Actor Attributes Job Level and Age

This section explores the centrality measures of the nodes in this knowledge network. Figure 7.39 illustrates the same network map as Figure 7.38, but with a focus on the node sizes. The node sizes represent the average degree centrality of the actors, i.e. the larger the node the more central the actor in relation to KT on sustainable construction.

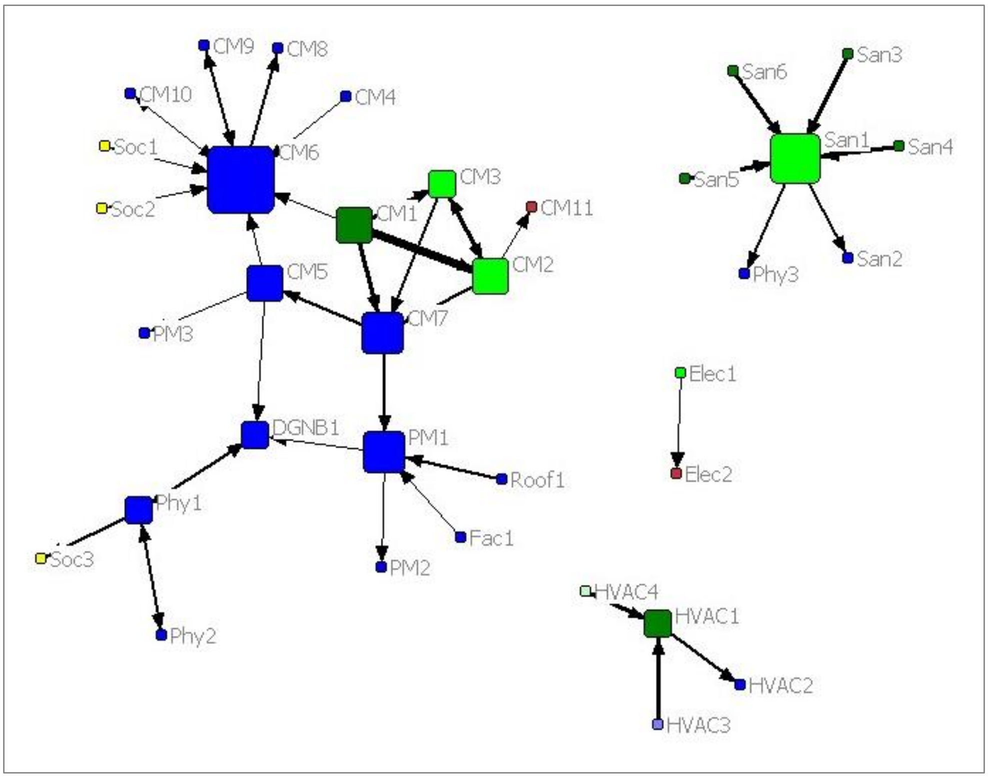


Figure 7.39: Knowledge Transfer Network of Case Study Germany3 – Degree Centrality

In order to support Figure 7.39, Table 7.50 presents the five most central actors for in-degree and out-degree centrality and their respective other value.

Table 7.50: Centrality Measures in Case Study Germany3

Actor	In-Degree	Actor	Out-Degree
San1	20	CM1	21
CM2	15	CM6	7
HVAC1	10	CM3	7
CM7	9	Phy1	7
CM6	8	HVAC3	5
CM3	6	San1	5
Phy1	5	CM2	4
CM1	0	CM7	4
HVAC3	0	HVAC1	2

It was vital to investigate whether the in- and out-degree values are linked with the actor attributes 'job level' and 'age group', as shown below.

Perceived experts:

- San1, supervisor at the sanitation contractors, age group: 45-54
- CM2, supervisor at the construction management company, age group: 45-54
- HVAC1, operative at the HVAC contractors, age group: 45-54
- CM7, project manager in charge, no data on age
- CM6, sustainability manager at the construction management company, age group: 45-54

Knowledge consumers or brokers:

- CM1, operative at the construction management company, age group: 55-64
- CM6, sustainability manager at the construction management company, age group: 45-54
- CM3, supervisor at the construction management company, age group: 45-54
- Phy1, buildings physician, age group: 35-44
- HVAC3, intern at the HVAC contractors, no data on age

Four out of five perceived experts belong to the age group 45-54, and also two of the knowledge consumers. Nonetheless the overall age range of the sample has to be considered against this result, i.e. 45.5% of all respondents are from this age group. Thus this could have biased the findings. This is the only case study that shows a link between age and being perceived as an expert on sustainable construction or a knowledge consumer.

San1 is the supervisor of the sanitation contractors. He/she is aware of the sustainability aim and received special training, which he/she also felt the need for. The sanitation company uses sustainable materials which San1 is also aware of. Yet the sanitation company is isolated as a component in this network. Hence San1 might be perceived as an expert, but only in his/her immediate work team.

CM6 is the sustainability manager of the construction management company. Of course he/she is aware of the sustainability aim and received special training, which he/she also felt the need for. Moreover CM6 is aware of the use of sustainable materials and technologies. This result is obviously as expected.

CM2 is a supervisor at the construction management company. Although he/she is aware of the importance of sustainability in this project, he/she did not receive any training or feels the need for it. Nonetheless CM2 is only aware of the use of sustainable materials/ technologies, *'because it says so on the packaging.'* This comment is similar to one from case study UK1 and shows a need for more information for the construction workforce.

HVAC1, an operative at the HVAC company, is perceived to be an expert on sustainable construction. He/she is aware of the sustainability aim of the project, but did not receive any specialised training. HVAC1 elaborates on this further by stating that '*there is no time for training'*. Yet HVAC1 states that they do not use any sustainable materials or technologies. When examining his/her KTs in detail, these are on techniques only.

It could have been assumed that the project manager in charge, CM7, is regarded as a general expert not only on sustainable construction, but as a person to contact with any overall queries. However, Figure 7.39 indicates that CM7 is not only giving, but also receiving a lot of knowledge on sustainable construction. When examining the kind of transferred knowledge in more detail, it shows that he/she seems to be an expert on mainly materials.

Regarding the knowledge consumers, CM1 is an operative at the construction management company. He/she is not aware of sustainability, did not receive any training nor feels the need for it. Nonetheless CM1 is aware of the use of sustainable materials and technologies.

CM3 is a supervisor at the construction management company. Although he/she is aware of the importance of sustainability in this project, he/she did not receive any training or feels the need for it. Moreover CM3 is aware of the use of sustainable materials/ technologies. This is very similar to CM2. Hence this suggests more training of the supervisors in order to raise their awareness and knowledge, as operatives largely depend on them.

Phy1 is the buildings physician, who is aware and had specialised training on sustainability. His/her high out-degree centrality value could indicate a role as a gatekeeper.

The following betweenness centrality calculations will investigate the gatekeepers, i.e. who passes on knowledge on sustainable construction in this construction project. The results are summarised in Table 7.51.

Table 7.51: Betweenness Measures in Case Study Germany3

Actor	**Betweenness**
CM6	107.33
CM5	80.83
DGNB1	67.33
PM1	66.33
CM7	60.33

Table 7.51 indicates that the main gatekeepers in this social network are:

- CM6, sustainability manager at the construction management company, age group: 45-54
- CM5, professional at the construction management company, age group: 35-44
- DGNB1, sustainability assessor of the project, no data on age
- PM1, project manager, no data on age
- CM7, project manager in charge, no data on age

Only two of these five actors also had high centrality values, i.e. CM6 and CM7. Nonetheless, this result confirms the earlier indication that CM6, the sustainability manager acts as a gatekeeper. His/her high centrality values prove the need for such a job role in a sustainable construction project. This is also supported by various statements of participants. For instance one respondent commented that *'due to the very substantial documentation requested by the DGNB, a supportive role and contact person for the sustainability certificate is needed.'* This statement is similar to comments made by the sustainability assessor in case study Germany1. Moreover this is in line with literature (Thomson *et al.,* 2010) that a sustainability manager could enhance the knowledge flow.

Nonetheless it is unclear why CM5, a professional from the construction company is supposed to be a gatekeeper. His/her network position is in between CM6, CM7 and DGNB1, as shown in Figure 7.39. Furthermore DGNB1 as the sustainability assessor is a gatekeeper as well. This is most likely due to his/her job role. In addition CM7 and PM1 also had a high in-degree centrality and seem to act as gatekeepers. This finding is as expected as both are project managers in charge.

In summary the various centrality calculations proved no clear connection between the actor attribute ‘job level’ and actor centrality. Experts and consumers were out of all job levels. Even one operative was perceived by his/her immediate work team as an expert on sustainable construction. However, all experts were aware of the sustainability aim. Hence this indicates a link and might suggest enhancing the overall awareness of the workforce. Moreover no link between actor centrality and training was detected. The gatekeepers in this case study are the sustainability manager, the sustainability assessor and the two project manager in charge.

7.4.3.7. Knowledge Sources

This section explores the knowledge sources further, i.e. their role and what kind of relationship exists between the knowledge source and receiver, and why this person was chosen to ask for advice on sustainable construction. Please see sections 3.4.1 and 5.3.1 for the discussion on knowledge repositories and sources. The results were analysed with content analysis and summarised in Table 7.52. In total the participants provided this information for 44 KTs, thus the number in the right hand column is the count.

Table 7.52: Knowledge Sources in Case Study Germany3

Coding	Count
Supervisor / Manager	12
Colleague (on another sustainable project)	10
Colleague (from another company)	6
Colleague (on this project)	5
Sustainability assessor	4
Social contact	4
Supply chain	2
Client	1
Total	**44**

Table 7.52 indicates that the most common knowledge source with a count of 12 was a manager or supervisor. This is followed by a colleague from the same company but working on another sustainability project (10). These results are not at all as expected and this is the first case study where a colleague is not the preferred knowledge source.

This outcome could be explained with the so-called ‘transactive memory’ termed by Wegner *et al.* (1991). Here the perceived competency of team members develops over time and experience of working together. As a result advice is sought more inside the team than outside. Thus this could relate to managers and supervisors, as well as colleagues from the same company but working on a different sustainable project. In addition the results on the choice of the knowledge source confirm the assertion from section 7.4.3.4 that the majority of the ties are relatively strong and thus facilitate the transfer of the large amount of tacit knowledge. This is in line with literature (Augier, Vendelø, 1999; Granovetter, 1973), i.e. tacit knowledge is best transferred through strong ties. The significant aspect of the results is that these strong ties exist in a sparse network, as it shows that tacit knowledge can be transferred through a sparse network, if it consists of strong ties. This is the fourth case study in which this result was observed. Consequently this questions existing literature and shows a need for more research on the relationship of network density, tie strength and tacit KT.

There is only a difference of one citation between colleagues from another company working at the same project (6) and colleagues/peers (5). This suggests an equal importance of both. Moreover the social network structure presented in Figure 7.38 supports this finding. It shows the various participating companies rather as separate components or parts of the main component, than cooperating with each other. As a result the findings on this issue confirm literature on the silo based structure of the industry (WBCSD, 2008) for this case study.

In addition it was further examined, whether the previously identified perceived experts and knowledge consumers differ in their knowledge source choice. The following list shows who they prefer to ask.

Perceived experts:

- San1 → supervisor
- CM2 → supervisor
- HVAC1 → supervisor
- CM7 → no data
- CM6 → colleague, supervisor, social contact

Knowledge consumers or brokers:

- CM1 → supervisor
- CM6 → colleague, supervisor, social contact
- CM3 → supervisor
- Phy1 → colleague, social contact
- HVAC3 → no data

Three experts and two knowledge consumers ask exclusively supervisors, while two other actors mention them amongst other knowledge sources. As supervisors and managers are the preferred knowledge sources in this case study, the findings on this issue concord with the main outcome. Therefore the choice of knowledge sources of central actors does not differ from other actor's choice. Hence there is no link between actor centrality and choice of knowledge source.

7.4.3.8. Relationship between Knowledge Transfer Methods and the Actor Attributes Age, Job Level and Actor Centrality

The methods first used in order to seek knowledge and secondly in order to receive this required knowledge were investigated. The respondents filled in the methods used for each KT, and were also given the opportunity to add methods, if they used others. However, no research participant in this case study added any method, whereas most of the offered methods have been used. This might suggest that all the important methods were covered in the data collection tools. Figure 7.40 depicts the findings on this issue.

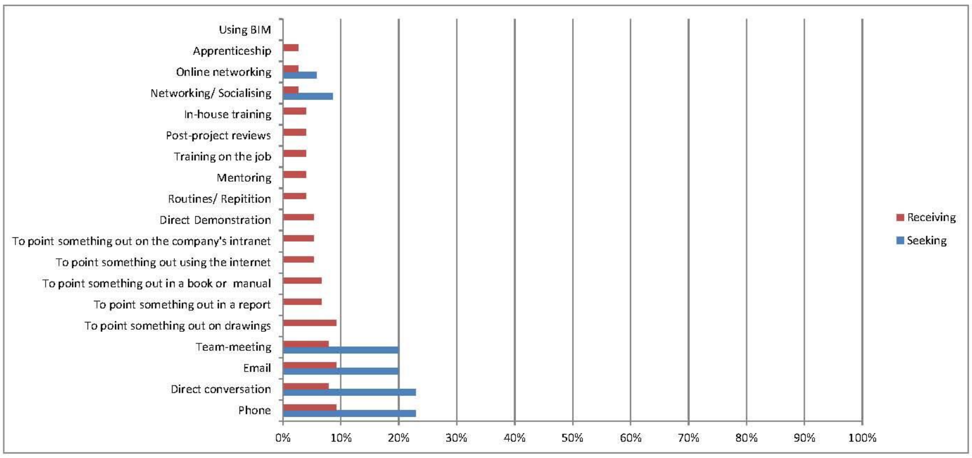


Figure 7.40: Knowledge Transfer Methods when seeking and receiving Knowledge in Case Study Germany3

Figure 7.40 shows that the participants sought knowledge on sustainable construction mainly by using phone, direct conversations, email and team meetings at a similar level. A small percentage of knowledge was sought through socialising and online networking. The knowledge given was transferred using nearly all methods to a similar amount. Apart from 'using BIM' all methods were used to transfer knowledge on sustainable construction.

The ten most used methods to receive knowledge on sustainable construction in this case study in order of frequency were:

- Phone
- Direct conversations
- Email
- Team meetings

- To point something out on a drawing
- To point something out in a report
- To point something out in a manual
- To point something out in the internet
- To point something out in the intranet
- Direct Demonstration

Most of these methods are, according to literature (Haldin-Herrgard, 2000; Egbu, 2004) used to transfer rather tacit knowledge. As a result the choice of these KT methods gives further evidence for the transfer of such a large amount of tacit knowledge (65.89%) through this sparse network, as discussed in section 7.4.3.4.

It is vital to investigate the relationships, if any, between the various chosen KT methods and actor attributes, such as ‘age group’, ‘job level’ and ‘actor centrality’. Thus the following figures present the cross tabulation of these. The figures only focus on the ten most frequently used methods which were identified previously.

Figure 7.41 illustrates the cross tabulation results between ‘age group’ and the chosen KT methods.

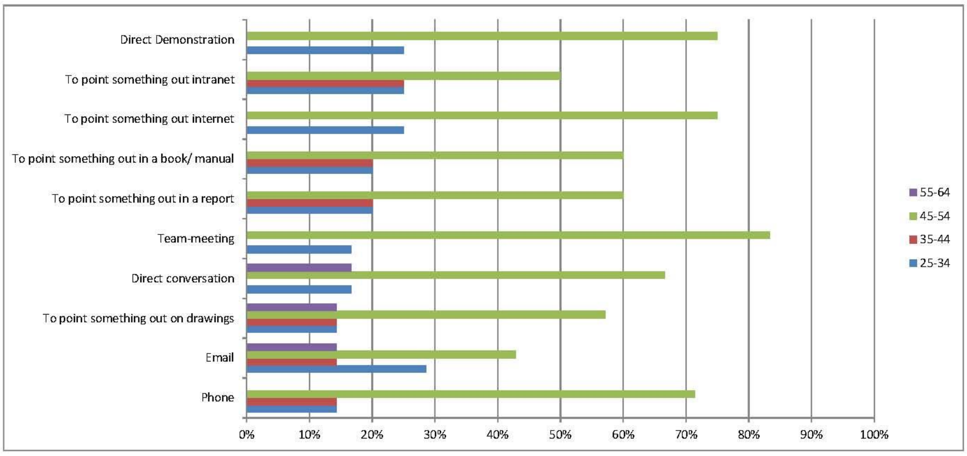


Figure 7.41: Knowledge Transfer Methods Cross Tabulation with Age Group in Case Study Germany3

As presented in Figure 7.41, there seems to be a difference in the methods chosen to transfer knowledge on sustainable construction depending on the age group. The youngest age group (25-34) and the one between 45 and 54 used all of the ten KT methods. The age group 35-44 used only six methods and the oldest age group only three. These results are contrary to the previous case study Germany2, where it was argued that more experience seem to enable actors to use a larger variety of KT methods. Nonetheless both case studies show a clear link between age and chosen KT methods. As argued before, an age difference between actors involved in a KT process influences its success (Riege, 2005). This could be for instance due to different preferences in the KT method choice.

Figure 7.42 presents the cross tabulation results between 'job level' and the chosen KT methods.

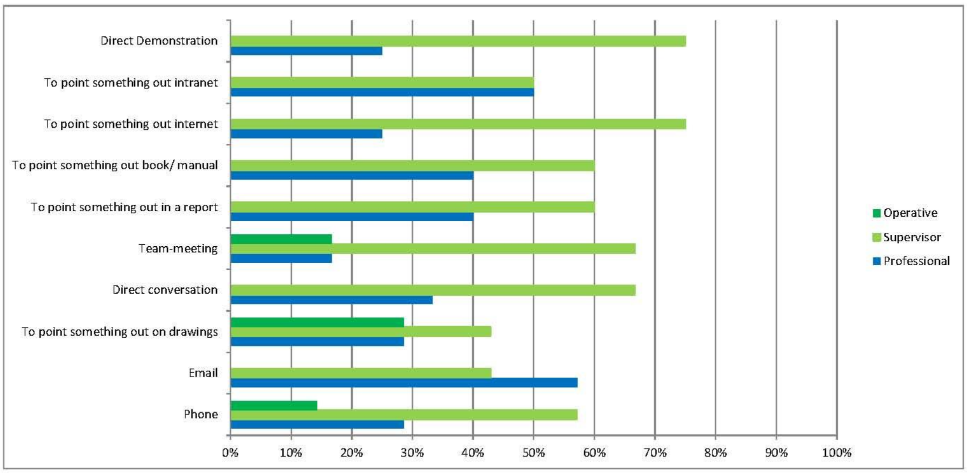


Figure 7.42: Knowledge Transfer Methods Cross Tabulation with Job Level in Case Study Germany3

Figure 7.42 indicates a difference in the KT methods depending on the job level. While professionals and supervisors use all of the ten KT methods, operatives only use three of these methods, i.e. phone, drawings and team meetings. This finding is similar to e.g. case study UK1. As presented in section 3.4.2.5, the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which also influences the KT and its success.

In section 7.4.3.6 the following five actors were identified as perceived experts on sustainable construction with the highest in-degree centrality. It was considered vital to examine their choice of KT methods in more detail.

- San1 → nearly all methods
- CM2 → nearly all methods
- HVAC1 →team meeting and direct conversation
- CM7 → no data
- CM6 → nearly all methods

This shows that the experts use in the main KT methods according to their job level. HVAC1 is an operative and prefers to use only two KT methods which is in line with the results depicted in Figure 7.42. The other perceived experts are either professionals or supervisors and use nearly all methods. Consequently the link between KT methods and job level seems to be more prominent than the one with actor centrality.

7.4.3.9. Duration of Knowledge Transfer

Table 7.53 summarises the results on the duration of the KTs occurred in this case study.

Table 7.53: Duration of Knowledge Transfers in Case Study Germany3

Time in Minutes	Count	Percentage
5	14	31.81%
10	12	27.27%
15	5	11.36%
20	3	6.81%
30	9	20.45%
No data	1	2.27%
Total	**44**	**100%**

The results for this case study show that 31.81% of the knowledge transfers on sustainable construction took only about five minutes. In addition 27.27% took about 10 minutes. No participant indicated any KT above 30 minutes. As mentioned before, this aspect is vital as construction projects are usually under a certain time pressure. Time constraints represent a main reason for KTs not to take place (Hansen, 2002; Riege, 2005; Lu, Sexton, 2007). However, this result indicates that it only takes on average up to ten minutes to answer questions on sustainable construction. Hence this finding suggests that this rather small amount of time might be worthwhile to consider, if it leads to an overall better built result.

7.4.4. Conclusion

This section presented the findings of the third German case study. It set out by giving a brief overview of the actor attributes of the respondents. The section then investigated to what extent the actor attributes and social network characteristics relate to each other and influenced the KT on sustainable construction in this case study.

Table 7.54: General Factors and Social Network Characteristics influencing KT on sustainable Construction in Case Study Germany3

	Awareness	Perceived Use of sustainable Material/ Technology	Training Received	Perceived Training Need	KT Methods	KT Source	Network Density	Job Level	Age
Age	x	x	x	x	√	NP	n/a	n/a	n/a
Gender	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Nationality	NP	NP	NP	NP	NP	NP	n/a	n/a	n/a
Education	Linked to job level								
Job level	x	x	x	x	√	x	n/a	n/a	n/a
Tie Contents	n/a	n/a	n/a	n/a	x	√	√	√	n/a
Actor Centrality	√	√	x	x	x	√	n/a	x	x
Awareness	n/a	NP	n/a	n/a	n/a	√	n/a	x	x

√ - linked; x – not linked; NP – link not prominent enough; n/a – not applicable/ investigated

In summary the analyses carried out in this case study seems to suggest that a number of factors may broadly influence each other and KT on sustainable construction. Table 7.54 provides a summary of the findings, which will be explained in the succeeding paragraphs.

In relation to so-called general influencing factors, such as gender and nationality, no remarkable results have been detected due to the nature of the sample, i.e. participants were all male and mostly German. However, as stated in section 3.4.1.1, the term nationality might be limited to fully capture the possible multi-cultural background of some respondents. Moreover the finding in section 7.4.3.2 confirmed that education defines job level later in life, hence these two actor attributes are linked. As a result succeeding analyses were conducted for job level only, though results represent both variables.

Furthermore 90.9% of the respondents in this case study were aware that the construction project strived to achieve a sustainability certificate. Furthermore 81.8% of the respondents were aware that their companies used sustainable materials or technologies. These results can be considered as very high compared to most other case studies. As a result it was not possible apart from actor centrality and awareness, to detect any prominent links between awareness and other variables.

Out of all respondents only 36.4% stated that they have had a special training on sustainable construction, while 72.7% did not feel the need for such specific skills. This finding is similar to case study Germany 1. Nonetheless the participants most likely did not feel the need for special training, as they were already very knowledgeable, shown through the high level of awareness. Those who actually received a specialised training were professionals and one supervisor.

In regards to the social network characteristics, similar to the previous case studies, the network density was found to be rather low with a value of 0.08. This indicates a sparse network with not much KT on sustainable construction occurring in this construction project. Tacit and explicit knowledge was transferred. In fact tacit knowledge was part of 65.89% of all KTs. In addition, the link between tie contents and KT methods, as the most frequently used KT methods confirm the transfer of tacit knowledge. As discussed in section 4.4.1 and 4.4.2, Granovetter (1973) and Reagans and McEvily (2003) argue that the tie characteristic, i.e. strength or weakness, determine the type of knowledge that is transferred. The choice of knowledge sources confirmed strong ties. Therefore this finding proves that it might be a sparse network but with strong ties, facilitating the transfer of large amounts of tacit knowledge similar to previous case studies. This finding goes along with the results of three other case studies. It is remarkable, as it shows that tacit knowledge can be transferred through a sparse network, if it consists of strong ties. Thus it is not in line with literature on network density, tie strength and tacit KT.

The most requested knowledge was on materials, techniques and a combination of all three subject areas. However, the link between actor attribute job level and tie contents was found to be not very prominent, as all job levels requested in the main knowledge on materials and techniques.

Centrality measures showed which actors are perceived as experts on sustainable construction by others, and which only consume knowledge. Here supervisors, professionals and operatives were in both groups, i.e. perceived as experts and knowledge consumers. As a result there seems to be no link between actor centrality and job level. Nonetheless actors with a high in-degree centrality i.e. perceived experts showed more awareness of sustainable construction, although they did not all receive special training or feel the need for such training. Hence no link between centrality and training was detected.

The betweenness centrality calculations identified the main gatekeeper of this construction project as the sustainability manager of the construction management company. The high degree and betweenness centrality values of him/her might suggest the need for a sustainability manager in addition to the architect or construction project manager as a contact person and to facilitate KT on sustainability issues in the project. This finding is similar to previous case studies and according to literature (Thomson *et al.,* 2010).

In regards to the relationship to the knowledge source, it was mainly the manager or supervisor, followed by a colleague from the same company but working on another sustainability project. These results are not at all as expected and the first case study where a colleague is not the preferred knowledge source.

Nearly all methods of the conceptual framework were used. 'DGNB Auditor training', 'seminar on specific products by manufacturers' and 'EnEV energy consultant training' were added by respondents. Moreover 'Hauptverband der Deutschen Bauindustrie', an institution of the German construction industry was mentioned. Institutions are already part of the conceptual framework as a possible knowledge source outside of the project. The age group of the research participants was observed to influence only the choice of KT methods, as different age groups preferred different KT methods. Moreover a link between job level and chosen KT methods was detected.

In regards to the duration of the KTs, 31.81% took only about five minutes. In addition 27.27% took about 10 minutes. No participant indicated any KT above 30 minutes in this case study. This aspect is vital as it suggests that this rather small amount of time might be worthwhile to invest, if it leads to an overall better built result.

The next part of this chapter discusses the differences and common grounds of all three German case studies

Key for Case Study Germany3

indicates research perticipants

Trade	Code	Job Level	Code
Project Manager	PM	Professional	PM1
		Professional	PM2
		Professional	PM3
DGNB	DGNB	Professional	DGNB1
Construction Manager	CM	Operative	CM1
		Supervisor	CM2
		Supervisor	CM3
		Professional	CM4
		Professional	CM5
		Professional (DGNB)	CM6
		Professional (PM)	CM7
		Professional	CM8
		Professional	CM9
		Professional	CM10
		Supply chain	CM11
Electrical Contractor	Elec	Supervisor	Elec1
		Supply chain	Elec2
Roofer	Roof	Professional	Roof1
Façade	Fac	Professional	Fac1
Building Physics	Phy	Professional	Phy1
		Professional	Phy2
		Professional	Phy3
HVAC	HVAC	Operative	HVAC1
		Supervisor	HVAC2
		Intern	HVAC3
		Apprentice	HVAC4
Plumber / sanitation contractors	San	Supervisor	San1
		Professional	San2
		Operative	San3
		Operative	San4
		Operative	San5
		Operative	San6
Contacts outside the project	Soc	Organisation CM6	Soc1
		Friend of CM6	Soc2
		DGNB Organisation Phy1	Soc3

7.5. Differences and Similarities of the German Case Studies

This chapter presented the analyses of the three German case studies (GE1-3). It has to be acknowledged that in case study GE1 the sample size is much smaller and it was not possible to collect data from operatives and apprentices. As a result the comparison of these three case studies is, similar to the UK ones, rather limited. Hence some conclusions derive from one or two case studies. Nevertheless certain trends emerged during analyses. These observations were taken into account and reflected on the conceptual framework, applying analytic generalization defined by Yin (2014). Figures 7.43 and 7.44 show sections of the original conceptual framework to ease the overview of the conclusions drawn from the German case studies.

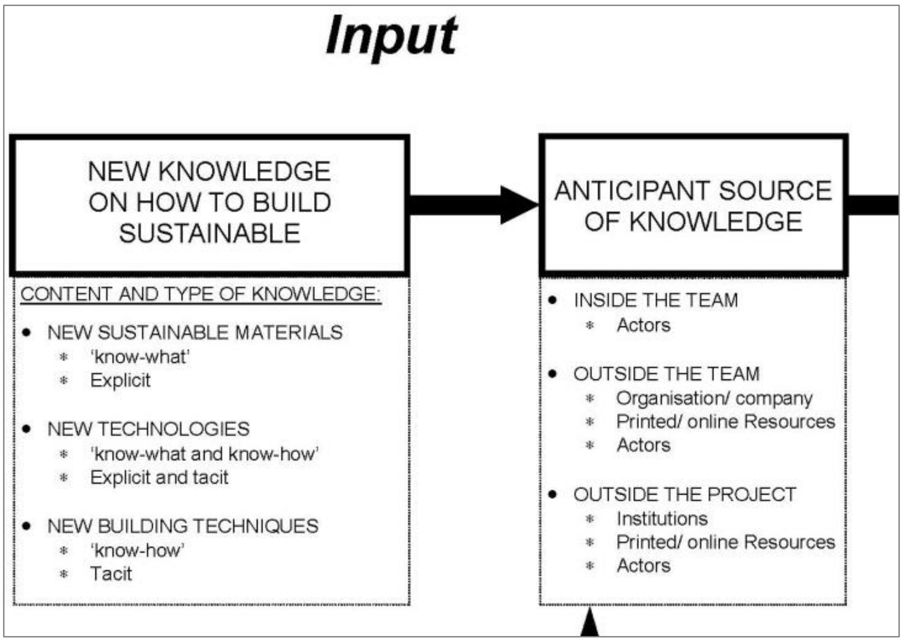


Figure 7.43: The Conceptual Framework – Input Section

The knowledge input section of the conceptual framework, illustrated in Figure 7.43, is devided into two parts, the new knowledge on sustainable construction and the anticipant source of this knowledge.

<u>New Knowledge on how to build sustainably</u>

Regarding the type and content of the new knowledge on sustainable construction the three categories and their combination were accepted and mostly used by all research participants. Yet, in GE1 the combination of materials and techniques, in GE2 the combination of technologies and techniques and in GE3 technologies and the combination of materials and technologies were not discussed at all. Moreover all three case studies differ in the discussed subject areas. In GE1 knowledge on materials was sought most. In GE2 a combination of all three subject areas, i.e.

materials, technologies and techniques, was by far most required. In case study GE3 the respondents discussed materials and techniques separately as well as combined.

In addition case studies GE2 and GE3 showed that it largely depends on the job level/educational background of the actors which subject area they require more knowledge on. However, this link was not found in the first German case study. Furthermore only the research findings of GE2 showed that more subject areas were covered by professionals, while operatives were rather discussing only one of the categories. This indicates a link between job level/educational background and tie contents.

The above mentioned observations appear to confirm the categories in which the new knowledge on sustainable construction was divided. The best aspect of these categories seems to be the variety of possible combinations of the three subject areas in order to designate exactly the knowledge transferred, as all respondents made good use of it.

<u>Anticipant Source of Knowledge</u>

The knowledge sources were identified by actor centrality measures, both degree and betweenness centrality. The results showed who is perceived by the others as an expert on sustainable construction, who acts as a gatekeeper and actively enhances the KT and who is just a knowledge consumer.

In case study GE2 supervisors and professionals were perceived as experts, whereas operatives were mostly knowledge consumers. As a result there seems to be a link between actor centrality and job level, as expected. As already argued in Chapter 2, specialist knowledge and thus specialists are required to deliver sustainable office buildings. The findings suggest that this is becoming the case, because supervisors of sub-contractors are regarded as experts. Nonetheless in GE3 all job levels were found in both groups. Furthermore the high centrality values of the sustainability managers and assessors in all three case studies might suggest hiring a sustainability manager in addition to the project manager/ architect in order to provide a contact person for sustainability issues in the construction project and enhance the KT in the project.

In regards to the relationship to the knowledge sources, those were in GE1 mainly supply chain members, DGNB contacts, colleagues and the client, all nearly at the same level. In GE2 a colleague was mostly asked, followed by a manager or supervisor. Yet, in GE3 the preferred knowledge sources were a manager or supervisor, followed by a colleague from the same company, but working on another sustainability project. This was not expected and it is the first case study where a colleague is not the preferred knowledge source. Nonetheless, it was argued that indicating the knowledge source also indicates to a certain extent the tie content trust, as by asking for advice the actor admits being less knowledgeable in the subject area (Borgatti, Cross, 2003). Trust enhances KT as argued in section 3.4.1.3. Hence it might not be a surprise that colleagues are chosen over managers and supervisors in GE2 and are an important source in GE1 as well. There might be more trust based relations amongst colleagues, than with someone from a superior job level. Moreover, as Wegner *et al.* (1991) argue, colleagues working on the same project together or in the same company might have developed a so-called 'transactive memory' i.e. they know 'who knows what' (Berends, 2005). canthus this could explain the preferred knowledge source in GE3. In addition the results on the choice of the knowledge source confirm the assertion that the majority of the ties are relatively strong and thus facilitate the transfer of the relatively large amount of tacit knowledge in all three case studies. This is in line with literature (Augier, Vendelø, 1999; Granovetter, 1973), i.e. tacit knowledge is best transferred through strong ties.

The silo based structure of construction industry indicated by various authors, was not found to be completely true in the particular context of KT on sustainable construction during construction stage in all case studies. Colleagues from other companies were a well used knowledge source when it comes to asking for advice on sustainable construction in two out of the three case studies. Nevertheless the network structure of all projects showed some silos, either in form of separate components or the various companies were sepratae parts of the main component.

Moreover the 'Hauptverband der Deutschen Bauindustrie' was named as a knowledge source which is an institution of the German construction industry. Institutions are indicated as a possible knowledge source in the conceptual framework, see Figure 7.43. Yet this was the first and only citation of an institution in all five case studies, apart from DGNB and BRE.

In summary regarding the relationship towards the knowledge sources on sustainable construction used in these case studies are to be found mainly inside the immediate work team, i.e. colleagues and supervisors/managers. Furthermore supply chain members, DGNB contacts and the client are well used sources in GE1. In case studies GE2 and GE3 actors outside the immediate work team but inside the same construction project, i.e. colleagues from other involved companies, were asked for advice as well. Moreover in GE3 colleagues from the same company but working on other sustainable projects are a valued source as well. As a result and similar to the UK case studies, printed and online resources shown in the original framework as knowledge sources should be better allocated in the KT process, methods/mechanisms section of the conceptual framework, which will be discussed next.

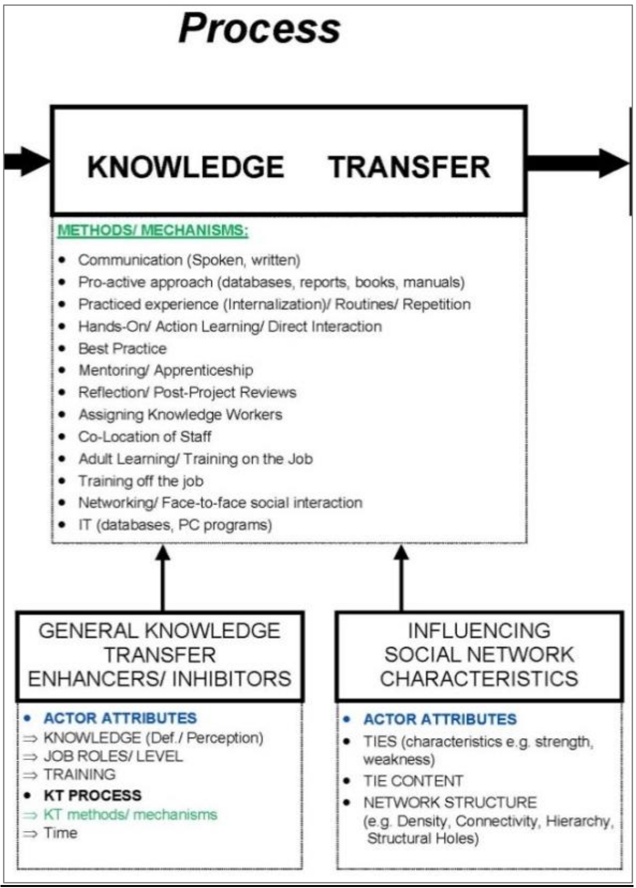


Figure 7.44: The Conceptual Framework – Process Section

<u>KT Process/ Methods and Mechanisms</u>

Figure 7.44 illustrates the KT Process section of the original conceptual framework. In section 3.4.2.3 several meachanisms drawn from literature were assumed to be appropriate for the KT on how to build sustainably. Thereafter methods were assigned to these mechanisms, as depicted in Table 7.55. The respondents indicated which of these KT methods they used to transfer sustainable construction knowledge.

Table 7.55: Knowledge Transfer Process/ Methods and Mechanisms

Mechanisms	Methods
Communication (Spoken, written)	Direct conversation Phone E-mail Team-Meeting
Pro-active approach (reports, books, manuals)	To point something out in a report To point something out in a book or instructions manual
Practiced experience (Internalization)/ Routines/ Repetition	Routines/ Repetition
Hands-On/ Action Learning/ Direct Interaction	Direct Demonstration To point something out on drawings
Best Practice/ Reflection	Post-Project Reviews
Mentoring/ Apprenticeship	Mentoring/ contact person with more work experience Apprenticeship Vocational Training/ School
Assigning Knowledge Workers	Assigning Knowledge Workers
Co-Location of Staff	Co-Location of Staff
Adult Learning/ Training on-the-job	Adult Learning/ Training on-the-job
Training off-the-job	Adult Learning
Networking/ Face-to-face social interaction	Networking/ Socialising Online networking
IT (databases, PC programs)	To point something out using the internet To point something out on the company's intranet Using BIM

First in all three case studies different methods were used in order to seek or to receive the requested knowledge. However, not all methods were used. In GE2 'BIM' and 'online networking', and in GE3 'BIM' were not used.

Furthermore in case study GE1 the following 11 methods were not used at all.

- BIM
- Co-location of staff / knowledge workers

- Post-project reviews
- Routines/ repetition
- Adult learning/ training on the job
- Vocational training / school
- Apprenticeship
- Reports
- Intranet
- Networking/ Socialising
- Books/ Manuals

The findings showed that the following methods were used most in order to receive knowledge on how to build sustainably. The order is according to frequency.

<u>Germany1</u>

- Direct conversation
- Phone
- Email
- Team meeting
- To point something out in the internet
- To point something out on a drawings
- Direct demonstration
- Mentoring

<u>Germany2</u>

- Phone
- Email
- Direct conversations
- Team meetings
- To point something out on a drawing
- Routine/ repetition
- Mentoring
- To point something out on the internet

<u>Germany3</u>

- Phone
- Direct conversations
- Email
- Team meetings
- To point something out on a drawing
- To point something out in a report
- To point something out in a manual
- To point something out in the internet
- To point something out in the intranet
- Direct Demonstration

As a result it is clear that the first four methods were the same in all three case studies, i.e. phone, email, direct conversation and team meeting. The following KT methods were added by some research participants:

- Training by the DGNB organisation
- LEED AP training
- EnEV energy consultant training
- Seminar on specific products by manufacturer

These four methods are apparently more likely part of adult learning, either on- or off-the-job, as indicated in the conceptual framework.

Moreover the methods chosen to transfer knowledge on sustainable construction differed depending on the ‘age group’ and the ‘job level’ of the actor. In GE1 mentoring is preferred by the age group 35-44, direct demonstration by the age group 25-34 and drawings by the group of 25-34. In GE2 the youngest age group, i.e. 16-24 only used three methods. This might suggest that with increasing work experience, employees learn how to transfer knowledge on sustainable construction through a larger variety of methods. Nonetheless in GE3 the youngest age group (25-34) and the one between 45 and 54 used all of the ten KT methods. The age group 35-44 used only six methods and the oldest only three. Thus this contradicts any assertions made for GE2. However, either way, both findings show a clear link between KT methods and age group. This is similar to the UK case studies. Here it was argued that age differences of participants in a KT can enhance or inhibit it (Riege, 2005), as presented in section 3.4.2.5. The findings confirm this and show that this could be due to for instance preferring to use different methods to transfer knowledge.

Furthermore there was a link between the choice of KT methods and job level in case studies GE1 and GE3 observed. Apart from three methods both job levels used all methods in GE1. Direct demonstration was preferred by supervisors. Professionals preferred mentoring and pointing something out on drawings. Furthermore in GE3 while professionals and supervisors use all of the ten KT methods, operatives only use three of these methods, i.e. phone, drawings and team meetings. Section 3.4.2.5 presented that the job levels of participants in a KT can impede the KT as to boundary issues (Fong, 2003), responsibilities (Bresnen *et al.,* 2003), competition (Kamara *et al.,* 2002) hierarchy (Riege, 2005) or power distance (Wilkesman *et al.,* 2009). These findings show that depending on the job level the actors in this case study prefer to use different methods to transfer knowledge which could also inhibit KT.

Additionally the findings showed that most central actors do not use different or more methods than others, but rather according to their job level.

In summary the results show that the KT was influenced by general actor attributes, as part of the general KT enhancers and inhibitors, such as job level and age of the involved actors. Regarding the social network characteristics actor centrality did not affect the choice of KT methods, while there was a link between tie contents and chosen methods detected. Most of the chosen methods are according to literature (e.g. Haldin-Herrgard, 2000; Egbu, 2004) used to transfer tacit knowledge. As a result the choice of these KT methods gives further indications to the tie contents. Thus this selection of KT methods provides further evidence of the transfer of a large amount of tacit knowledge through the rather sparse networks in all case studies.

<u>General Knowledge Transfer Enhancers/ Inhibitors</u>

In relation to so-called general influencing factors ‘actor attributes’, such as gender and nationality, no remarkable results have been detected due to the nature of the samples, i.e. participants were mostly male and German. Although some respondents might have a multi-cultural background, this might not be reflected in the results on nationality. Yet, as stated in section 3.4.1.1, the participants expressed their citizenship though not necessarily their cultural background. Moreover the findings of all three case studies confirmed that education defines job level later in life, hence these two actor attributes are linked. Nonetheless educational background not part of the original conceptual framework yet.

The variable ‘definition and perception of knowledge’ was tested by asking questions on the awareness of sustainability and the use of sustainble materials/technologies. The awareness of the respondents was relatively high in all three case studies. Moreover sustainable materials and technolgies named and used by the respondents were mostly sustainable, which proved a good knowledge base as long as they used it in their everyday worklife.

In addition there are a few remarkable findings when looking at case study GE2 only, due to the respondents’ job level. For instance the differences in awareness towards sustainable construction varied depending on the job level, i.e. the unawareness was only to be found in the construction workforce. Moreover 42.9% who did not know whether they used sustainable materials/technologies were of the construction workforce as well. This confirms the lower level awareness of operatives and their supervisors and suggests better informing or training them in order to raise the awareness. Additionally whether an actor is perceived as a knowledge source appears to depend on the job level as well, with more professionals and supervisors being knowledge sources in GE2. Moreover the findings suggest a relationship between tie contents and job levels, as knowledge on certain subject areas was required more frequently by certain job levels. This was also the case for GE3.

In GE1 33.3% received training on sustainable construction, while no one felt the need for such training. In GE2 only 9.5% received training and 63.2% indicated it is not necessary. In case study GE3 36.4% had specialised training, but 72.7% implied that there is no need for it.

The findings on the factor 'time' show that most KTs only require 10 minutes, whilst most others are up to 20 minutes. This suggests that this relatively small amount of time might be worthwhile if it improves the quality of the built outcome. Moreover this could imply that questions on sustainable construction do not require long explanations, but are rather solved quickly.

In summary the findings show that most general knoweledge transfer enhancer/inhibitors affected each other and the KT process. Although it was not possible to detect this for personal actor attributes, such as gender and nationality due to the nature of the samples, it was proven that age, awareness, job level/educational background and training were linked to each other and defined the KT methods chosen, the knowledge subject area requested, the network position and the choice of knowledge sources.

Influencing Social Network Characteristics

Some of the influencing social network characteristics were already discussed in the previous paragraphs as they influenced the actor attributes or the KT methods. For instance, a link between tie contents and job level was identified. Moreover actor centrality was used to determine the knowledge sources. Yet there was no link observed between actor centrality and the choice of KT methods. Furthermore a link between tie contents and KT methods was detected, as the most frequently used KT methods proved the transfer of a large amount of tacit knowledge in all three case studies. Additionally the findings showed that most central actors do not use different or more methods than others.

The discussed subject areas give further indications on the knowledge type transferred and thus can be linked back to the tie characteristics and the network structure. Similar to the UK case studies, the relatively large amount of transferred tacit knowledge through the sparse networks of all case studies is a remarkable finding and could indicate strong ties. As Augier and Vendelø (1999) put forward that tacit knowledge is best transferred through strong ties. This is also supported by Granovetter (1973) and Fernie *et al.* (2003), as discussed in section 4.4.2. Strong ties can be defined by long, close relationships with high trust (Granovetter, 1973). Therefore the results on the choice of the knowledge sources confirmed the assertion that the majority of ties are relatively strong and facilitate this KT. It is remarkable that the results of two German case studies show that these strong ties exist in a sparse network, as it demonstrates that tacit knowledge can be transferred through a sparse network, if it consists of strong ties. Moreover these findings are similar to the two UK case studies. Therefore this questions existing literature and shows a need for more research on the matter of network density, tie strength and tacit KT.

Concluding in terms of whether social network characteristics affected the KT, it was observed in the German case studies that the strength of ties, the tie content and the network structure did indeed have an effect on KT on sustainable construction.

CHAPTER 8

DISCUSSION OF KEY FINDINGS AND CONCLUSION

8.1. Introduction

This chapter sets out with providing an account of the key findings that emerged from the empirical study presented in Chapters 6 and 7 and discuss them in the context of the comparative nature of this research and in relation to existing knowledge. The second part of this chapter presents the revised conceptual framework and argues the changes made as a consequence of the findings. This is followed by recommendations on how to use the framework in practice, in order to fulfil the last research objective. The third part of this chapter presents how the aim and objectives were achieved. This is followed by the contribution to knowledge made. Thereafter the various limitations of this study are explained. This thesis concludes with recommendations for further research.

8.2. Comparison and Discussion of the Key Findings for Germany and the UK

The key findings that emerged through analysis are further examined in this section and discussed in the context of existing knowledge. The focus lies on determining common grounds and differences of how knowledge on building sustainably was transferred in the three German and two UK case studies. One of the strengths of this study is that the findings were replicated through testing the conceptual framework with data from five separate construction projects to provide sufficient replication of the findings. As Borgatti and Cross (2003) state most of the previous research in the social network tradition have largely drawn conclusions based on a single social network within one organization in one industry. This research exceeds this by far. The results of each country were already discussed separately in section 6.4 and 7.5. Tables 8.1 and 8.2 summarise the key findings for both countries which will be discussed in the succeeding sections.

Table 8.1: Key Research Findings on General Knowledge Transfer Enhancers and Inhibitors per Country

		UK		Germany		
		UK1	**UK2**	**GE1**	**GE2**	**GE3**
General Knowledge Transfer Enhancers/Inhibitors	**Awareness of sustainability**	51.3% Linked to job level	72.7%	100%	71.4% Linked to job level	90.9%
	Use of sustainable materials and technologies	56.4% Linked to job level	90.9%	33.3%	38.1% Linked to job level	81.8%
	Educational background	Linked to job level	Linked to job level	Linked to job level	Linked to job level	Linked to job level
	Training received	20.5% Linked to age, job level	27.3% Linked to age	33.3%	9.5%	36.4%
	Training needs	31.4%	54.5%	0%	10.5%	27.3%
	KT Methods	Linked to age, job level, but not to actor centrality	Linked to age, but not to job level, actor centrality	Linked to age, but not to job level, actor centrality	Linked to age, job level, but not to actor centrality	Linked to age, job level, but not to actor centrality
	Duration of KT	-	10 min (47.17%)	10 min (46.7%)	10 min up to 20 min (36.2%)	5 min (31.81%) 10 min (27.27%)

8.2.1. General Knowledge Transfer Enhancers and Inhibitors

As argued in Chapter 2 the emerging need for high quality performing sustainable buildings seems to be in contrast with more and more evidence on built results failing the design intent (Bordass, Leaman, 2013). The lack of knowledge and awareness of practitioners in the field was identified as one of the main barriers towards sustainable construction (WBCSD, 2009; Rodrigues *et al.,* 2012). Capturing and transferring knowledge from one stage of a building's lifecycle to the next is already difficult. A considerable knowledge loss occurs during this process (Wallbank, Price, 2007). Additionally sustainability issues render this even more challenging, as they change the required knowledge and create new knowledge. Thus the increasing importance of sustainability has important consequences not only on the technological practice of construction industry, but also on its structure and its communication channels (Rohrbacher, 2001). As a result it was argued that a better co-operation and integration of various stakeholders is required through enhanced knowledge sharing from project inception to completion (Rohrbacher, 2001; Häkkinen, Belloni, 2011). Therefore it was further explored in Chapter 3 how KT between the various practitioners can be enhanced. The chapter concluded by presenting general KT enhancers/inhibitors found in literature and categorised into the two main groups ‘actor attributes’ and ‘KT process’. The field work findings on these variables will now be discussed.

8.2.1.1. Actor Attributes

Personal Actor Attributes (age, gender, nationality)

It was argued by various authors that cultural differences and gender of KT participants affect KT in terms of power distance, performance orientation, in-group collectivism and uncertainty avoidance (Wilkesmann *et al.,* 2009; Ruddy, 2000; Riege, 2005). Nonetheless the research participants were mainly male and natives of the countries where the projects were located. As a result it was not possible to further examine the influence of gender and nationality on KT. However, it has to be acknowledged that the term nationality might be limited to fully capture the multi-cultural background of some respondents.

Riege (2005) put forward that age differences of individuals participating in KT can affect its success. The findings confirmed this statement, as in all five case studies the age influenced the choice of KT methods. This clearly affects KT itself, as participants in a KT process might not prefer the same methods.

Moreover the findings of the two UK case studies showed a link between the age and the received training. In case study UK1 it was noticed that in the main the younger age group 25-34 did not think they received any training. In case study UK2 the few respondents that received training, i.e. in form of adult learning, were in the age group 45-54. These results could imply that sustainability issues have not yet been implemented enough in the vocational training. This leads to suggesting an improvement of the vocational training. Regarding the German case studies there was no link between age and training detected.

Knowledge Definition and Perception
(Awareness of sustainability/ Use of sustainable materials and technologies)

Egbu (2004) stated that an incoherent knowledge vision and an unawareness of the possessed knowledge can impede KT. The knowledge definition and perception was tested through questions on awareness of the sustainability aim of the project and the use of sustainable materials and technologies.

As depicted in Table 8.1 the awareness was overall higher in the three German case studies. Moreover the results of case studies UK1 and GE2 (the ones with the richest data in terms of sample number and represented job level), show that the awareness is linked to the job level. It is noteworthy that in both case studies only operatives and supervisors were not aware of sustainability in the projects. The same link was detected for the use of sustainable materials and technologies. The results evidently suggest better informing all project participants and especially the construction workforce of the importance of sustainability and the use of sustainable materials in order to raise the overall awareness and support a coherent knowledge vision. This could then enhance KT on sustainable construction, in line with Egbu (2004).

Educational Background and Job Level

The findings of all five case studies confirmed a clear link between educational background and job level, i.e. the educational background defined the job level of the respondents. Moreover the findings showed that the actor attribute job level/educational background had overall the most influence on other variables. Here the awareness towards sustainability, the training received, actor centrality, i.e. being a knowledge expert or consumer, the knowledge subject area required and the KT methods preferred were influenced by job level/educational background of the KT participant. These links were more prominent in case studies with more job levels represented by research participants. There are two possible explanations for the importance of these variables:

First, there could be a lack of quality in the formal education. Egbu (2004) argues that the formal education and training affects KT. Moreover various authors criticised a lack of skilled professionals to deliver sustainable buildings and emphasize the need to up-skill practitioners in the field (WBCSD, 2009; Kurul *et al.,* 2011; Thomson *et al.,* 2010; Rodrigues *et al.,* 2012). Thus the findings, especially in relation to awareness and use of sustainable materials provide further evidence that there is still a lack of skilled staff. Furthermore the results clearly confirm the previous suggestions to improve the vocational training, in line with Steedman (2011) and better implement sustainability principles.

Second, as discussed in Chapter 3, the job level could influence KT in terms of boundaries (Fong, 2003), definitions of roles and responsibilities (Bresnen *et al.,* 2003), rivalries and competition (Kamara *et al.,* 2002), hierarchy and power distance (Riege, 2005; Wilkesmann *et al.,* 2009). Yet, the findings presented in Table 8.1 show that job level effects KT in terms of influencing the awareness towards sustainability, the training received, being a knowledge source or consumer, the subject areas requested and the KT methods used. Therefore the findings add to the discussion of how the job level of KT participants affects its success.

Training on sustainable construction

Training has an obvious effect on knowledge as it should increase through it (Ugwu, 2005). Thus training then can affect KT (Egbu, 2004). There was an overall lack of agreement whether special training on sustainable construction is actually needed in all five case studies. Moreover it was not clear to respondents of the UK case studies what such training involves, as they named all received training without differentiating whether it was on sustainability. Whereas the respondents of the German case studies were more certain how to describe sustainable construction training. Nonetheless the German respondents listed overall a smaller variety of training than the UK ones.

As presented in Table 8.1, the requirement for training was less in the German case studies. This could be because the training received was slightly higher in the case studies GE1 and GE3 with over 30%. Case study GE2 is the one with the overall lowest training rate. Here only two participants, one professional and one apprentice, received training on sustainable construction. The apprentice indicated that it was part of his/her vocational training, whereas the professional was trained as a DGNB auditor. Neither the training received nor the training needs had a prominent link to age or job level in all three German case studies.

As mentioned previously, in both UK case studies the received training was linked to age. The younger age group 25-34 did not receive any training in case study UK1. In case study UK2 the few respondents that received training were in the age group 45-54. As argued before, these findings might suggest improving the vocational training through better implementation of sustainability principles. Additionally the results of case study UK1 showed a link between job level and training received, with mainly operatives being trained. Yet this finding has to be seen in the context of these respondents naming any training received without differentiating whether it was on sustainability. Thus this supports the finding on the unawareness within the job level of operatives.

The national differences in this point can be explained with the strong legal background in Germany, regarding the implementation of sustainability principles. This goes back to 1976 with the first energy savings ordinance, as presented in section 2.4.1. Thus the practitioners in the field had a greater need and more time to adapt their businesses compared to the UK ones. Moreover this larger time frame enabled the vocational training in Germany to implement sustainability principles over the years. Hence it can be argued that there seems to be no need for additional special sustainable construction training, as the basic level of knowledge and awareness of sustainability is gained through the vocational training or university education. Therefore it explains why additional training in the German case studies was rather on specific materials/technologies or in order to become a specialist such as a DGNB auditor. This can also be evidenced through various statements of research participants.

8.2.1.2. Knowledge Transfer Process

Knowledge Transfer Methods

The literature identifies appropriate methods, tools and mechanisms that are needed for a successful KT (Bresnen *et al.,* 2003; Egbu, 2004; Ugwu, 2005; Huang, Newell, 2003). Thus the methods used to request and receive knowledge were investigated. This allowed filtering the methods and gaining results on only the methods used to transfer knowledge. The results showed a difference in KT methods used to request and to transfer/ receive knowledge.

First most methods used in all five case studies are according to literature (Haldin-Herrgard, 2000; Egbu, 2004) rather used to transfer tacit knowledge. Thus the selection of KT methods provides further evidence for the transferred knowledge types, discussed below under 'tie contents'.

Secondly all offered KT methods were used in both UK case studies, while the German participants used fewer methods. This finding is similar to the results of the training, where the German respondents used a smaller variety as well. In all five case studies the most used KT methods were phone, direct conversation, emails and team meetings.

As indicated in Table 8.1, the results showed that age affected the choice of KT methods in all five case studies. Riege (2005) put forward that age differences of participants in a KT influence its success. Consequently the findings confirm this and argue that this could be due to preferring different KT methods. Nonetheless the methods preferred by each age group differ in all case studies. It is therefore not possible to determine specific preferred methods by age group.

Moreover the results show a link between job level and choice of KT methods in three case studies, i.e. UK1, GE2 and GE3. As previously argued, literature asserts an influence of job level on KT. Thus the findings add to these discussions as they show that additionally job level affects KT in terms of preferring to use different KT methods.

Duration of Knowledge Transfer

Previous studies stated that participants have argued with general time constraints for KTs not taking place (Hansen, 2002; Riege, 2005; Lu, Sexton, 2007). This aspect is vital as construction projects are usually under a certain time pressure.

However, the results depicted in Table 8.1 proved that it only takes on average about ten minutes to answer questions on sustainable construction. This result was similar in both countries. Hence this finding suggests that this rather small amount of time might be worthwhile to consider, if it could lead to an overall better performing built result. Additionally this result implies that most questions on sustainable construction seem to be not that complex, if they can be solved in such a short amount of time. As such this finding adds to quantifying the average duration of KTs on sustainable construction, even though just in the context of these four case studies.

8.2.2. Influencing Social Network Characteristics

As knowledge is a set of shared beliefs constructed through social interactions and embedded within social contexts, Fong (2003) declares that social networks are the most important vehicle for knowledge exchange, with team members deeply reliant upon colleagues and friends as resources for generating knowledge. Moreover Fernie *et al.* (2003) indicate that knowledge is personal, and hence knowledge sharing takes place through interaction of individuals. Within a project environment the personal knowledge of whom to contact in order to receive the required knowledge appears to be vital (Bresnen *et al.*, 2003). Thus social community plays a vital role in enhancing or inhibiting KT (ibid). Consequently Chapter 4 explored the possibilities social networks offer to enhance KT on how to build sustainably. Various social network models and concepts combined with KT were discussed in terms of their apply ability to the problem statement, i.e. overcoming the performance gap between sustainable design intent and built result. The concepts drew attention to social network characteristics that influence KT. The findings on these variables are summarised in Table 8.2 and will now be discussed in detail.

Table 8.2: Key Research Findings on Social Network Characteristics per Country

		UK		**Germany**		
		UK1	**UK2**	**GE1**	**GE2**	**GE3**
Influencing Social Network Characteristics	**Actor Centrality**	Linked to job level	Not prominent	Not prominent	Linked to Job level	
	Perceived Experts	Supervisor electrical contractors Supervisor BMS company Construction project manager Supervisor Brickwork Company Operative BMS company	Sustainability manager Supervisor logistics company Construction project manager in charge Professional construction management company Supervisor lift company	DGNB assessor/ building physics Architect Supervisor plasterworks DGNB assessor 2 Professional HVAC and plumbing	Supervisor HVAC company Construction project manager DGNB assessor Professional construction management company Professional construction management company	Supervisor sanitation company Supervisor construction management company Operative HVAC Project manager Sustainability manager
	Relationship to Knowledge Sources	Colleague Manager Colleague from another company Supervisor	Colleague	Supply chain member DGNB contact Colleague Client	Colleague Supervisor/ Manager Colleague from another company	Supervisor/ Manager Colleague on another sustainable project
	Network Density	0.03 Sparse Linked to tie contents	0.06 Sparse Linked to tie contents	0.05 Sparse Linked to tie contents	0.05 Sparse Linked to tie contents	0.08 Sparse Linked to tie contents
	Tie Contents - Most discussed subject areas and tacit knowledge part	Materials and a combination of all three subject areas Linked to Job level 55.2% tacit	A combination of all three subject areas Linked to Job level 58.82% tacit	Materials 39.01% tacit	A combination of all three subject areas Linked to Job level 55.18% tacit	Materials Techniques A combination of all three subject areas 65.89% tacit

Actor Centrality and Knowledge Sources

Actor centrality measures, both degree and betweenness centrality, were used to identify the knowledge sources. Moreover the results showed who is perceived by others as an expert on sustainable construction, who acts as a gatekeeper and actively enhances KT and who is just a knowledge consumer. Additionally the relationship to the knowledge source was inquired in order to retrieve more information on the strength of the tie.

As presented in Table 8.1 colleagues were overall the most frequently consulted knowledge source on sustainable construction in three out of five case studies. Participants in case study GE1 preferred to ask supply chain members, as they encountered problems with the definition of sustainability levels of materials. Nonetheless DGNB contacts and colleagues were consulted almost at the same level. This leaves case study GE3 as the only exception. Here the participants tend to ask their manager/supervisor followed by a colleague from the same company but working on a different sustainable project. Hence the knowledge source might not be a colleague that they work together on a daily basis, though still someone from the same company.

It was argued that indicating the knowledge source also indicates to a certain extent the tie content trust, as by asking for advice the actor admits being less knowledgeable in the subject area (Borgatti, Cross, 2003). Trust does affect KT as argued in section 3.4.1. Hence it might not be a surprise that colleagues are chosen over managers and supervisors in four case studies. There might be more trust based relations amongst colleagues, than with someone from a superior job level. Moreover colleague working together, i.e. on the same project or in the same company, might have developed a so-called 'transactive memory' (Wegner *et al.,* 1991), i.e. they know 'who knows what' (Berends, 2005). As a result, it can be argued that the choice of the knowledge source indicates strong ties in all case studies, defined by trust, lengthy timeframes and close relationships (Augier, Vendelø, 1999; Granovetter, 1973). Reagans and McEvily (2003) argue that the motivation to assist such a contact is greater than with weak ties. Moreover strong ties facilitate the transfer of tacit knowledge (Augier, Vendelø, 1999). The discussion on the findings of tie contents below will explore this relationship further.

Additionally the findings of case studies UK1 and GE2 (the case studies with the richest data in terms of sample number and represented job levels) showed that supervisors and professionals were perceived as experts, whereas operatives were mostly knowledge consumers. As a result job level seems to influence actor centrality. As already argued in Chapter 2, specialist knowledge and thus specialists are required to deliver sustainable office buildings. The findings suggest that this is becoming the case, as supervisors of sub-contractors are regarded as experts amongst others in both case studies. Moreover this confirms the previously discussed results on awareness towards sustainability, which showed a higher unawareness within the group of operatives.

The case studies UK2 and GE3 employed a sustainability manager. The high degree and betweenness centrality values of the sustainability manager in these two case studies show the importance of such a key person for sustainability issues and their possibilities to enhance KT on sustainable construction in the project as a gatekeeper. As previously pointed out, sustainability issues are changing the way construction industry conducts its business (Rohrbacher, 2001). Thomson *et al.* (2010) suggest employing a sustainability manager or assessor to have a contact person for sustainability issues. The findings support this view partially, as statements from case study UK2 and GE1 showed that the actual sustainability assessor is too occupied with the assessment and not always on-site to be a contact person on a daily basis. As a result it can be suggested to additionally employ a sustainability manager. In case studies UK2 and GE3 this was done by the construction management company. This could imply that rather than creating a new job role for every construction project, it is sufficient for the companies to employ one expert to work on a number of projects.

Network Density

As presented in Table 8.1 the network density of all case studies is relatively low, varying from 0.03 in case study UK1 to 0.08 in GE3. This shows sparse networks regarding the KT on sustainable construction in all five projects. It was argued in section 4.4.1 that the network density influences KT in terms of the type of knowledge being transferred (Reagans, McEvily, 2003), the diversity of transferred knowledge (Nahapiet, Ghoshal, 1998), how much knowledge the actors have in common (Portes, 1998) and possibilities for innovation (Alguezaui, Filieri, 2010). The following discussion on tie contents examines these influences further.

Tie Contents and Characteristics

Different types of knowledge to be found in literature were identified in Chapter 3 and applied to the field of sustainable construction. Three subject areas of knowledge, emerged through sustainability issues in the built environment were determined as sustainable materials, technologies and techniques. A combination of explicit and tacit knowledge as to know-what and know-how were allocated to these three areas. It was then examined which subject areas were more required which gave further indications of the knowledge types transferred.

The results summarised in Table 8.1 show a variation for the most requested knowledge areas in the five case studies. ‘Materials’ was the most requested knowledge area in case studies UK1, GE1 and GE3. A combination of all three subject areas was discussed in UK1, UK2, GE2 and GE3. Moreover knowledge on techniques was required in GE3.

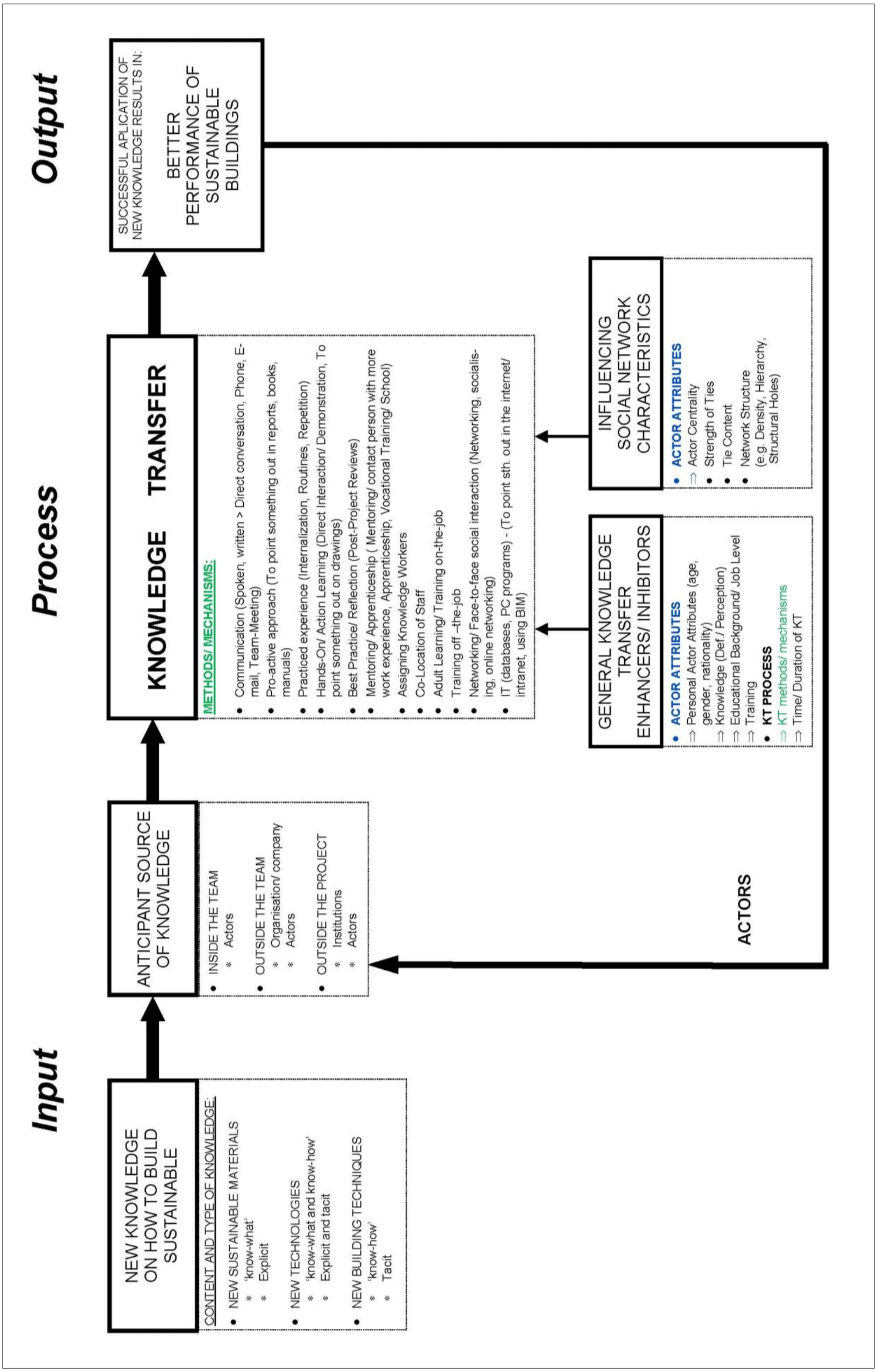
In addition the findings presented in Table 8.1 indicate a link between job level and required knowledge area for case studies UK1, UK2 and GE2. Nonetheless the requested knowledge areas by job level differ in these case studies. It is therefore not possible to determine specific knowledge areas required by job level.

The discussed subject areas give further indications on the knowledge type transferred and thus can be linked back to the tie characteristics and the network structure. As argued in section 5.3.1 the new knowledge on sustainable materials only is considered to be explicit. Hence it can be better transferred through a sparse network with weak ties (Fernie *et al.,* 2003). This is in accordance to the findings of case studies UK1, GE1 and GE3. However, the new knowledge on techniques was defined as purely tacit in section 5.3.1. Table 8.1 indicates the part of the transferred tacit knowledge for each case study. Apart from case study GE1 tacit knowledge was part of over 55% of all KTs in the other four case studies. This result is also supported by the chosen KT methods. As argued previously, most methods used in all five case studies are according to literature (Haldin-Herrgard, 2000; Egbu, 2004) better to transfer tacit knowledge. The rather large amount of transferred tacit knowledge through the sparse networks is a remarkable finding. Augier and Vendelø (1999) put forward that tacit knowledge is best transferred through strong ties. This is also supported by Granovetter (1973) and Fernie *et al.* (2003), as discussed in section 4.4.2. Therefore the results on the knowledge sources, as mainly colleagues confirm the strong ties that facilitated the transfer of this type of knowledge. As a result the findings on this issue show that tacit knowledge can be transferred through a sparse network, if it consists of strong ties. Therefore this questions existing literature and shows a need for more research on the relationship of network density, tie strength and tacit KT.

8.3. The Conceptual Framework

8.3.1 Revision of the Framework

The initial framework on KT of how to build sustainably was developed through an extensive literature review on the key areas of sustainable construction, KT and social network theory. Please see section 5.3 for more details on the development of the original framework. This conceptual framework was used as a starting point and tested in practice through case study data in line with the fourth research objective presented in Chapter 1. This process is also called analytic generalization, in line with Yin (2014), as case study data was used to confirm the framework get suggestions on how to amend it, in order to make it more applicable to practice. New influencing factors emerged, such as duration of the KT. Moreover links and dependencies between various factors were either confirmed or excluded through the findings. As a result a final framework was developed which is presented in Figure 8.1.



Input
Process
Output
NEW KNOWLEDGE ON HOW TO BUILD SUSTAINABLE
CONTENT AND TYPE OF KNOWLEDGE:
• NEW SUSTAINABLE MATERIALS
* 'know-what'
* Explicit
• NEW TECHNOLOGIES
* 'know-what and know-how'
* Explicit and tacit
• NEW BUILDING TECHNIQUES
* 'know-how'
* Tacit
ANTICIPANT SOURCE OF KNOWLEDGE
• INSIDE THE TEAM
* Actors
• OUTSIDE THE TEAM
* Organisation/ company
* Actors
• OUTSIDE THE PROJECT
* Institutions
* Actors
KNOWLEDGE TRANSFER
METHODS/ MECHANISMS:
• Communication (Spoken, written > Direct conversation, Phone, E-mail, Team-Meeting)
• Pro-active approach (To point something out in reports, books, manuals)
• Practiced experience (Internalization, Routines, Repetition)
• Hands-On/ Action Learning (Direct Interaction/ Demonstration, To point something out on drawings)
• Best Practice/ Reflection (Post-Project Reviews)
• Mentoring/ Apprenticeship (Mentoring/ contact person with more work experience, Apprenticeship, Vocational Training/ School)
• Assigning Knowledge Workers
• Co-Location of Staff
• Adult Learning/ Training on-the-job
• Training off –the-job
• Networking/ Face-to-face social interaction (Networking, socialising, online networking)
• IT (databases, PC programs) - (To point sth. out in the internet/ intranet, using BIM)
GENERAL KNOWLEDGE TRANSFER ENHANCERS/ INHIBITORS
• ACTOR ATTRIBUTES
⇒ Personal Actor Attributes (age, gender, nationality)
⇒ Knowledge (Def./ Perception)
⇒ Educational Background/ Job Level
⇒ Training
• KT PROCESS
⇒ KT methods/ mechanisms
⇒ Time/ Duration of KT
INFLUENCING SOCIAL NETWORK CHARACTERISTICS
• ACTOR ATTRIBUTES
⇒ Actor Centrality
• Strength of Ties
• Tie Content
• Network Structure (e.g. Density, Hierarchy, Structural Holes)
SUCCESSFUL APLICATION OF NEW KNOWLEDGE RESULTS IN:
BETTER PERFORMANCE OF SUSTAINABLE BUILDINGS
ACTORS

Figure 8.1: The revised Framework

As argued in sections 6.4 and 7.5, in the main the conceptual framework was found to reflect practice. For instance, the three subject areas of new knowledge on sustainable construction were accepted and used by all research participants. The best aspect of these seem to be the variety of possible combinations of the three subject areas, in order to designate exactly which knowledge was discussed. Moreover the knowledge sources and their location were confirmed as mainly actors, either inside the immediate work team, on the same project or outside the project. Furthermore the KT methods and influencing factors were for the most part affirmed as well. Nonetheless, the following minor changes and amendments were made during and after the analysis stage.

In order to ease the understanding of the framework and to make it more accessible it was found best to specify the methods in the KT box of the conceptual framework. As a result the methods were added in brackets behind the mechanisms in the framework.

The findings of all five case studies showed that ‘printed and online resources’ were rather used as KT methods than knowledge sources. As a result ‘printed and online resources’ were taken from the input section and were allocated in the KT process, methods/mechanisms section of the framework, i.e. as a method part of the pro-active approach and IT.

A few research participants mentioned the following training through which they received knowledge on sustainable construction. Some of this training was part of the KT methods in the original framework, such as on-the-job training. Others such as institutions like the DGNB were already located in the original framework as knowledge sources. These statements were observed as a trend throughout the five case studies and seen as a further confirmation of the training methods and knowledge sources in the framework.

UK1
On-the-job training
1 day course in-house
Training by manufacturer
Only directions are offered
Learnt by asking different people
Learnt my skills on-site and from other workers, and learnt a lot by watching others

UK2
CPD (continuing professional development) courses
On-the-job training
1 day course in-house
Post project reviews
Training by manufacturer
Workshops with specialist consultants

GE1
DGNB auditor training

GE2
Routines/ repetition/ experience
1 day course in-house
Vocational training
DGNB Auditor/ LEED AP training

GE3
In-house course
Seminar on specific products by manufacturers
DGNB Auditor
'Hauptverband der Deutschen Bauindustrie'
EnEV (German energy saving ordinance) energy consultant training

The findings of all five case studies proved a strong link between the educational background and job level. Moreover bivariate analyses with the variable job level/educational background showed a strong influence on other variables and KT itself. As a result the actor attribute 'educational background' was added to the general knowledge transfer enhancers/inhibitors next to job level.

In order to render the framework more accessible personal actor attributes were written out, i.e. age, gender and nationality were put in brackets behind 'personal actor attributes'. Riege (2005) put forward that age differences of KT participants can impede the KT. The findings confirmed this and showed that in this context it could be due to preferring different methods to transfer knowledge on sustainable construction. The nature of the samples, i.e. mostly male and British or German, did not allow to examine the influences of gender and nationality in more detail. Yet, literature argued that these factors could influence KT and since it was not proven that they do not influence KT, it was decided to keep them in the framework.

The factor ‘time’ was found to be more important than initially thought of. During the data collection and analysis ‘time’ or rather ‘time constraints’ consistently appeared and seemed to be one of the main reasons for some KTs not taking place. There is a difference between general time constraints and the time duration of KTs, although both factors belong to the category ‘time’. This resulted in collecting data on the duration of KTs. Therefore ‘duration’ was added to the general KT enhancers/inhibitors next to time.

The data from the first UK case study was the richest in terms of sample number and job levels represented by the research participants. The findings suggested to sort the KT methods according to the actor attribute ‘job level’. Unfortunately the nature of the sample of the other case studies did not allow drawing such a conclusion with complete certainty. As a result the KT process box of the framework was not amended accordingly.

8.3.2 How to use the Framework in Practice

The purpose of the framework is to enhance KT within construction projects of sustainable office buildings. Moreover it could be applied to other sustainable construction projects of any building type and to refurbishments. Furthermore the framework was designed in such a way that it could be used in any project environment by simply replacing the knowledge on sustainable construction with whatever knowledge is needed to be transferred within a project team. In summary the framework can be seen as a management tool to support and enhance the transfer of project knowledge.

The findings of this study clearly suggest benefits could be derived from employing a sustainability manager to enhance the KT on sustainable construction in the project. One of the tasks assigned to this key person could be to adapt this framework to each specific construction project and provide it to the project manager, team leaders and supervisors at project inception, so they can promote KT on building sustainably within their team and across team boundaries. The framework could then be used during the construction project as follows.

First during the design stage the various sustainable materials and technologies are specified. Hence the knowledge input box can be adapted specifically to each project by listing the sustainable materials and technologies, and the techniques required for their installation. This can be done by the sustainability manager in cooperation with the sustainability assessor and the architect.

Thereafter the knowledge sources can be defined as either specialists on these materials and technologies in the various work teams, or actors that are due to their role, e.g. supervisors, most likely to be approached as a knowledge source. The findings suggest that these knowledge sources should receive additional training on the materials, technologies and techniques, if required. Additionally the knowledge sources should be allocated more time for KT.

Furthermore the sustainability manager could facilitate a workshop for the potential knowledge sources to make them aware of influencing factors, such as personal actor attributes and social network characteristics and how to overcome them. Besides it was found vital for a successful KT to advise the knowledge sources to be more aware of choosing the right KT methods for each knowledge consumer. Thus they can be given a wider selection of KT methods from the framework in this workshop.

Finally it can be suggested to facilitate more training for all participants to raise the general awareness and basic knowledge and understanding of sustainable construction, and on specific materials and technologies used in a particular project. Training was found to be important for both, knowledge consumers and experts.

If the framework is applied in combination with SNA conducted by a researcher during the project, similar to this study, it enables a clear identification of knowledge sources, experts and consumers in the various work teams. As a result more directed follow-up activities would be possible. Müller-Prothmann (2007) recommends for instance better integration or exit of isolated actors, promotion of central actors as coordinators or moderators, stronger focus on the required topic, strengthening sub-groups by providing additional resources. This could be especially interesting as a long-term approach for main contractors aiming to improve their performance over time.

From a researcher’s point of view, the conceptual framework was found to be very useful during the whole PhD project. It helped to keep the focus on the main aim and objectives of the research throughout the literature review. Additionally it supported the successful design of the data collection tools. Finally it guided the process of analysis. As such the framework can not only be applied in practice in terms of actual construction projects, but it can also assist researchers while examining KT processes in their entirety.

8.4. Adressing the Aim and Objectives

The rationale of this study derives from sustainability fundamentally transforming construction industries worldwide. The nature of product demanded by tenants, constructed by developers, required by governments and favoured by capital providers is changing and becoming more complex. Seamless transfer of knowledge between the more divergent set of actors involved in these projects is required to deal with this complexity. The gap between the performance of green buildings as designed and as built could be interpreted as an indication that this transfer is not flawless. Nowadays almost every actor involved in the construction process claims to strive for sustainability. However, the way they perceive and translate it into practice varies widely between different construction project participants. Therefore a better understanding of how knowledge on sustainable construction is transferred and adopted is needed. A subsequent enhancement of this process could offer a solution to secure a certain standard of sustainable building quality. Previous research indicated that social networks influence KT as knowledge is personal, and hence KT takes place through the interaction of individuals. Moreover SNA provides the means to map the knowledge flow in a project environment and hence enables an understanding of how to enhance it. As a result SNA was used in order to understand how knowledge is transferred in construction project teams delivering sustainable office buildings in Germany and the UK.

With this background in mind, the main aim of this research project was to investigate the extent to which social networks can influence knowledge transfer within project teams delivering new office buildings to sustainable building standards in Germany and the UK.

The objectives for achieving this were:

- To identify the key concepts in the area of knowledge transfer and social networks.
- To identify factors that influence knowledge transfer.
- To develop a conceptual framework based on these key concepts and factors.
- To test the conceptual framework in practice.
- To make recommendations on how to use the framework in order to enhance knowledge transfer in practice.

Chapter 2 provides the rationale of this study by presenting an overview of the benefits and barriers towards sustainable construction and concludes by highlighting the main problem as the performance gap between intended sustainable design and underperforming built output. A possible reason for this could be the lack of knowledge and awareness of practitioners in the field and the difficulty to capture and transfer this specialised knowledge between all project participants and across all stages of a construction project. As a result and in order to achieve the first two objectives, a literature review was undertaken on the domains of knowledge management and transfer, and social network theory, as presented in Chapters 3 and 4.

Chapter 3 discusses the key concepts in the area of KM with a particular focus on KT. This was a means to achieve a better understanding of factors that influence KT in line with the second research objective. Moreover this literature review led to defining and categorising the knowledge on sustainable construction as sustainable materials, technologies and techniques. A combination of explicit and tacit knowledge in terms of know-what and know-how were allocated to these three areas. This provided a more purposeful research approach, allowed a deeper insight into the required knowledge and gave indications of the knowledge types transferred. Additionally the knowledge sources and various KT methods were identified in literature. General KT influencing factors were determined as follows:

- Actor Attributes
    - Knowledge (Definition/ Perception)
    - Job roles / level
    - Training
- KT Process
    - KT methods/ mechanisms
    - Time

The key concepts of social networks were reviewed in Chapter 4 and led to identifying influencing social network characteristics, such as:

- Network Structure (e.g. Density, Connectivity, Hierarchy, Structural Holes)
- Tie characteristics (e.g. Strength, Weakness)
- Actor Attributes (e.g. Centrality)
- Tie content

The third objective was achieved by developing the original conceptual framework out of these influencing factors, as presented in section 5.3.

This was then, in accordance with the fourth research objective tested in practice through case study data of two case studies in the UK and three in Germany. Here it was investigated to what extent the actor attributes and social network characteristics relate to each other and influenced KT on sustainable construction. The empirical findings are presented in Chapters 6 and 7. The key findings are summarised in the following section.

The achievement of the fifth and last research objective was demonstrated in section 8.3.2 by advising how the revised framework can be used in practice.

8.5. Contribution to Knowledge

8.5.1. Theoretical Contribution

This research contributes to literature on KT specifically from a social network perspective. In doing so it responds to the gap in knowledge pointed out in Chapter 1 and argued by various authors, i.e. to combine concepts of network structure and relatedness in tie contents regarding specialised knowledge (Seufert *et al.*, 1999; Hansen, 2002; Bresnen *et al.*, 2003; Inkpen and Tsang, 2005). In particular the findings add to the following discussions:

The lack of skilled professionals to deliver sustainable buildings (WBCSD, 2009; Kurul *et al.,* 2011; Thomson et al., 2010; Rodrigues *et al.,* 2012) was confirmed through low levels of awareness towards sustainability and towards the use of sustainable materials and technologies, especially in the UK construction workforce.

The findings of this research confirm literature suggesting employing a sustainability manager as a key contact (Thomson *et al*, 2010). The SNA results show that a sustainability manager can enhance KT on sustainable construction as a gatekeeper.

The findings on the duration of the KTs give an indication to the average time needed to transfer knowledge on sustainable construction, even though just in the context of four case studies.

The KT process can be influenced by the age and job level of the participants due to them preferring different KT methods. Moreover the results showed a difference in KT methods used to request and to transfer/ receive knowledge. Thus the findings add to literature on KT methods. Additionally literature on KT methods for transferring tacit knowledge was confirmed through the results (Haldin-Herrgard, 2000; Egbu, 2004).

Furthermore this study facilitates the understanding of knowledge contents and types of sustainable construction knowledge. As presented in section 3.2, the following three subject areas were determined and knowledge types allocated:

- sustainable materials – explicit, know-what
- sustainable technologies – explicit and tacit, know-what and know-how
- techniques - tacit, know-how

All research participants made good use of these. A main advantage is the variety of possible combinations of the three subject areas in order to designate exactly the knowledge transferred.

The findings showed that large amounts of tacit knowledge were transferred through strong ties in sparse networks. On the one hand this supports assertions made by Granovetter (1973) and Augier and Vendelø (1999) that strong ties are needed to facilitate tacit KT. However, on the other hand the results show that strong ties do not necessarily equate a dense network, but can exist in a very sparse network as well. As a result this questions literature and indicates a need for further research and discussion on network density, tie strength and tacit KT.

To the best of the author's knowledge, the research is the first of its kind comparing KT in construction teams delivering sustainable office buildings in Germany and the UK.

8.5.2. Methodological Contribution

The framework is the most important output of this research in terms of both contribution to knowledge and practice. From a researcher's point of view, the conceptual framework was found to be very useful during the whole PhD project. During the development stage the framework helped to keep the focus on the main aim and objectives of the research throughout the literature review. Additionally it supported the successful design of the data collection tools. Finally the framework guided the process of analysis. The findings confirm that the use of the framework enables researchers to examine the KT in sustainable construction projects in its entirety. Whereas the application of the framework to practice, i.e. sustainable construction projects, enables a better understanding of the KT between the various participating companies and allows making recommendations of enhancing it. Following *analytic generalization,* i.e. the use of theory to generalize from case studies (Yin, 2014), the results of the case studies were used to confirm, though slightly modify the conceptual framework.

8.5.3. Contribution in Terms of Policy Implication

The findings discussed in section 8.2 showed a lack of awareness and knowledge of sustainable construction which was slightly higher in the UK case studies. This confirms literature as various authors criticised a lack of skilled professionals to deliver sustainable buildings and emphasize the need to up-skill practitioners in the field (WBCSD, 2009; Kurul *et al.,* 2011; Thomson *et al.,* 2010; Rodrigues *et al.,* 2012). This could be related to the argument that the UK vocational training is in quality and time worse compared to continental Europe, as presented in section 2.5.2. This statement is supported through the findings of three German case studies which showed an overall higher level of awareness and knowledge towards sustainable construction. As a result a possible policy suggestion could be a better implementation of sustainable principles into the UK vocational training for construction jobs. As such the German vocational training could be taken as a best practice example, in line with Steedman (2011).

In general the findings have the potential to support the implementation of environmental policies, such as achieving EU 2020 targets, through showing ways on how to enhance the sustainability knowledge and awareness of various stakeholders.

8.5.4. Contribution in Terms of Publication Output

As the output from this research project was mainly this thesis, including the methodology, empirical data and key findings, with respect to influencing factors of KT, a copy was offered to the participating companies as a reward in return for their participation. Further contribution in terms of publication output was made in form of two conference papers.

Paper 1: ‘Knowledge transfer in construction project teams delivering sustainable office buildings in the UK and Germany’, presented at the Sixth International Conference on Construction in the 21st Century (CITC-VI) “Construction Challenges in the New Decade”, Kuala Lumpur, Malaysia, July 2011.

Paper 2: ‘Knowledge transfer in project teams delivering office buildings to sustainable building standards’, presented at the Sustainable Building and Construction Conference, Coventry, UK, July 2013.

8.6. Limitations of the Research

In conducting this research two kinds of limitations were encountered. As a result this section is sub-divided and first discusses methodological limitations, followed by field limitations.

8.6.1. Methodological Limitations

As the findings from this research are relevant to a range of areas, i.e. sustainable construction, knowledge transfer and social network analysis, the impact is rather broad. On grounds of these limitations there might be difficulties in translating the findings into specific guidelines for policy, see section 8.5.3.

Furthermore, it was not possible in this research to asses a formal monitoring of ‘before’ and ‘after’. Therefore no evidenced conclusions can be drawn regarding the potential success of the application of the framework.

8.6.2. Field Limitations

In neither of the two countries were more projects available and willing for research purposes than the ones chosen in this study. On the one hand it was not expected to be so challenging to get access to construction projects during the research design stage. On the other hand this fact rendered the sampling of the case studies as unnecessary, which might have caused a potential bias in terms of the findings. However, since only new office developments aiming for a sustainability certificate were contacted, the projects were already in itself to a certain level comparable and fulfilled the main sampling criteria presented in section 5.4.

Regarding the UK, a total number of 41 construction projects were contacted through their BREEAM assessors. This was followed by using social contacts of the researcher and Oxford Brookes University staff. Additionally the BRE was also contacted several times, though unfortunately showed no interest in supporting this research.

In regards to Germany, a total number of 29 construction projects were contacted through their DGNB assessors. This was followed by contacting investors, architects and consultants. The DGNB showed initially high interest in supporting the study and publishing the results on their website. Nevertheless the contact person changed jobs during the research project, thus this was not further followed-up.

As previously stated, the refusal rate was extremely high. On average it took about six- 12 months getting access to a construction project. It was considered important to understand the reasoning behind this in order to improve the approach strategy. The following observations were made and could be considered as a side research output itself:

- No time/ tight schedule
- Other concerns at the moment, such as problems with the architect
- Contact person lost/ changed his/her job
- Data protection/ confidentiality/ sensitivity of collected data (mainly in Germany)
- Afraid to lose their competitive advantage
- German companies did not see an advantage of a comparison with UK companies
- Afraid of additional work/ problems/ responsibilities through participation in research
- Did not understand advantages or reasoning for participating in research
- No monetary refund for participation
- No marketing for their company, to be named in publications as best practice
- Researcher being a woman: no facilities on-site

- Health and safety of researcher on site (PPE and CSCS)
- Trustworthiness of researcher – requested CV

These statements go partially along with literature (Lynn, 2008). Figure 9.1 summarises influencing aspects on survey co-operation of research participants. The respondent, i.e. sample member is located in the centre of the figure with the social environment, survey design, interviewer and interaction with interviewer influencing his/her decision whether to participate in the study.

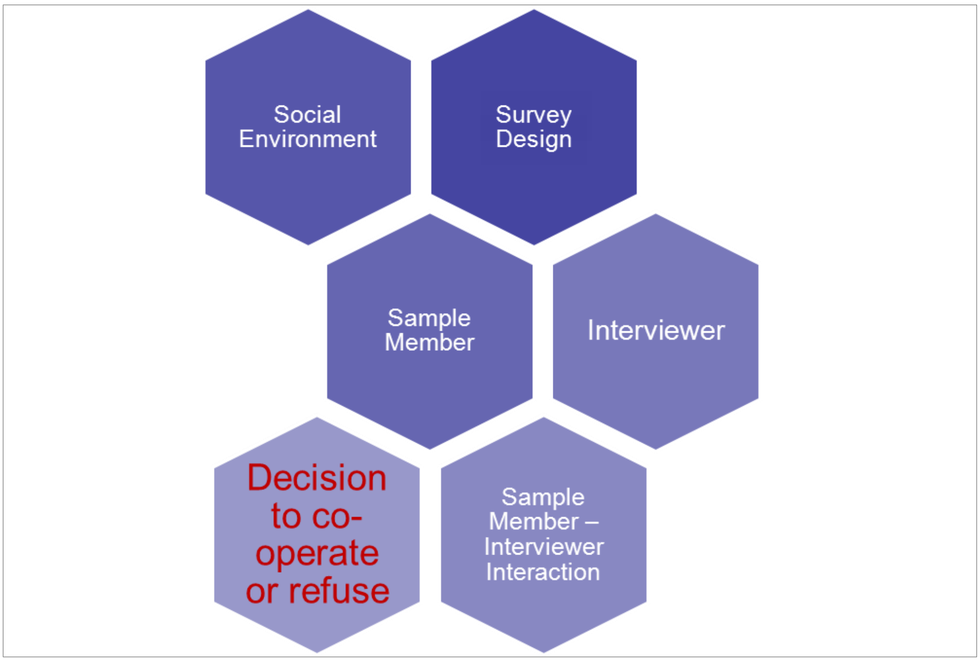


Figure 8.2: A conceptual framework for Survey Co-operation (adapted from Groves and Couper, 1998; in Lynn, 2008)

As a result these reasons for refusal led to re-designing the participant information sheet, in order to show the advantages of participating in this research and explain the data protection in more detail. Additionally it involved amending the data collection process itself and its tools as efficiently as possible. Hence during fieldwork the data collection process was as fast as possible and tried not to interfere with the construction process. This was then also communicated through the participant information sheet and in any emails, letters, phone calls or meetings. Each construction project was visited for one day only. The researcher sat in an on-site port-a-cabin office, offering the project participants to come by and fill in the questionnaire whenever they could spare the time. More questionnaires were collected through emails afterwards. Nonetheless as a result it was not possible to conduct follow-up interviews after the analysis of the questionnaire data to get more insights on network positions or materials/technologies used, as stated in Chapters 6 and 7. Moreover it was in some case studies not even possible to ask for more research participants from a broader range of job levels. The participant information sheet, the consent form and questionnaire can be found in Appendices A, B and C.

8.7. Further Research Recommendations

The aim of this research was to examine to what extent social network characteristics influence KT on sustainable construction in project teams delivering new office buildings to sustainable building standards in Germany and the UK. Due to the very specific focus of a PhD and its scale and time constraints, it naturally reveals other areas and aspects for further examination. Particularly as the previous section 8.6 has outlined the limitations and hence suggested opportunities for further research, there is considerable scope for it.

Strengthening the overall research design by conducting follow-up interviews with the knowledge experts and consumers identified through SNA could provide deeper insights into the matter, e.g. further explanations for network positions or more suggestions to enhance the KT. Additionally the applicability of the findings could be raised by a larger number of case studies, hence a replication of the findings. Furthermore the research could be extended to include other building types and refurbishments.

Moreover measuring the performance of the built outcome could offer a possibility of linking it with the knowledge network findings. Thus the results could provide further insights in terms of which knowledge network resulted in what performance level of the built outcome.

Additionally a long-term study could provide an understanding on how a project team improves their performance through the application of the developed framework. This could be done by e.g. accompanying a main contractor for a number of projects from start to completion with preferably the same employees.

The issue of transferring sustainability knowledge in construction project teams can of course also be examined using alternative methodological approaches. This would allow a wider discussion through triangulation of the various results. For instance, this could be done by linking purely qualitative research, i.e. interviews, with analysis of documentation sources, such as protocols of meetings and email exchange.

There seems to be a gap in knowledge to what extent the performance gap is due to the construction process or to user behaviour. Thus there is scope for examining both in one project in order to determine to what extent the construction process and/ or the user behaviour caused the performance gap.

Finally there is potential to explore further on the scope of the wider applicability of the framework to other project environments outside of the AEC sector.

References

Abraham, A., Hassanien, A. and Snášel, V. (2010). *Computational Social Network Analysis: Trends, Tools and Research Advances.* Dordrecht, Heidelberg, London, New York: Springer

Alguezaui, S. and Filieri, R. (2010). Investigating the Role of Social Capital in Innovation: Sparse versus Dense network. *Journal of Knowledge Management* 14 (6), pp.891-909.

Argote, L. and Ingram, P. (2000). Knowledge Transfer: A Basis for Competitive Advantage in Firms. *Organizational Behaviour and Human Decision Processes* 82 (1), pp.150-169.

Atkinson, C., Yates, A. and Wyatt, M. (2009). *Sustainability in the Built Environment. An introduction to its definition and measurement.* BRE.

Atkinson, P. and Delamont, S. (2008). Analytic Perspectives. In: Denzin, N., Lincoln, Y. (ed.) *Collecting and Interpreting Qualitative Materials.* 3rd edition. Sage.

Augier, M. and Vendelø, M. T. (1999). Networks, Cognition and Management of tacit knowledge. *Journal of Knowledge Management* 3 (4), pp.252-261.

Berends, H. (2005). Exploring Knowledge Sharing: Moves, Problem Solving and Justification. *Knowledge Management Research & Practice* 3, pp.97-105.

Bordass, W., Cohen, R. and Field, J. (2004). Energy Performance of Non-Domestic Buildings: Closing the Credibility Gap. *Building Performance Congress*. Frankfurt am Main, Germany, 19-24 April.

Bordass, W. and Leaman, A. (2013). A New Professionalism: Remedy or Fantasy? Guest editorial for New Professionalism. *Building Research and Information Journal* 41 (1), pp.1-7.

Borgatti, S., Everett, M. and Freeman, L. (2002). *UCINET.* Harvard, MA: Analytic Technologies.

Borgatti, S. and Cross, R. (2003). A Relational View of Information Seeking and Learning in Social Networks. *Management Science* 49 (4), pp.432-445.

Bou-Llusar, J. and Segarra-Cipres, M. (2006). Strategic Knowledge Transfer and its Implications for Competitive Advantage: An Integrative Conceptual Framework. *Journal of Knowledge Management* 10 (4), pp.100-112.

Bourdieu, P. (1983). Ökonomisches Kapital, kulturelles Kapital, soziales Kapital. In: Kreckel, R. (ed.) *Soziale Ungleichheiten.* Göttingen, pp.183-198.

BRE (2013). *BREEAM In-Use. Driving sustainability in existing buildings.* BRE, Watford.

Bresnen *et al.* (2003). Social practices and the Management of Knowledge in Project Environments. *International Journal of Project Management* (21), pp.157-166.

Brookes, N. *et al.* (2006). Social Processes, Patterns and Practices and Project Knowledge Management: A theoretical Framework and an Empirical Investigation. *International Journal of Project Management* 24, pp.474-482.

Brundtland, G. (1987). *Our common future - Report of the World Commission on Environment and Development.* General Assembly, United Nations.

Bryman, A. and Burgess, R. (1996). Developments in qualitative data analysis: an Introduction. In: Bryman, A., Burgess, R. (ed.) *Analysing Qualitative Data.* London and New York: Routledge.

Bryman, A. and Bell, E. (2007). *Business Research Methods.* 2nd ed. Oxford: Oxford University Press.

Bryman, A. (2008). *Social Research Methods.* 2nd edition. Oxford: Oxford University Press.

Cadman, D. (2007). *The Carbon Challenge.* Centre for the Study of Sustainable Building.

Carrillo, P. and Anumba, C. (2002). Knowledge Management in the AEC Sector: an Exploration of the Mergers and Acquisitions Context. *Knowledge and Process Management* 9 (3), pp.149-161.

Cohen, R. *et al.* (2008). Implementation of EPBD (Energy Performance Building Directive) Article 7.3 in Germany and the UK: Comparison of Methodologies and

Procedures. *Improving Energy Efficiency in Commercial Buildings (IEECB).* Frankfurt am Main, Germany, 10-11 April.

Cohen, W. and Levinthal, D. (1990). Absorptive Capacity: A new Perspective on Learning and Innovation. *Administrative Science Quarterly* 35 (1), pp.128-152.

Dainty, A. (2008). Methodological Pluralism in Construction Management Research. In: Knight, A., Ruddock, L. (ed.) *Advanced Research Methods in the Built Environment*. Wiley-Blackwell.

Davenport, T. and Prusak, L. (1998). *Working Knowledge: How Organizations manage what they know.* Boston, Mass.: Harvard Business School Press

DCLG (2009). *Zero carbon for new non-domestic buildings.* Consultation on policy options. London: Department for Communities and Local Government.

De Leeuw, E., Hox, J. and Dillman, D. (2008). *International Handbook of Survey Methodology.* New York, London: Taylor & Francis Group.

De Vaus, D. (2002). Analysing social science data. In Denzin, N., Lincoln, Y. (2008). *Collecting and Interpreting Qualitative Materials.* London: SAGE.

Denzin, N. and Lincoln, Y. (2000). *Handbook of Qualitative Research.* 2nd ed. Sage.

Despres, C. and Chauvel, D. (1999). Knowledge Management(s). *Journal of Knowledge Management* 3 (2), pp.110-120.

Despres, C. and Chauvel, D. (2002). A Review of Survey Research in Knowledge Management: 1997-2001. *Journal of Knowledge Management* 6 (3), pp.207-223.

DGNB (2009) DGNB_eng_finished_091102.pdf sourced online [PowerPoint presentation]. Available at: http://www.dgnb.de (Accessed: 03 November 2009).

DGNB (2009) DGNB_praesentation_20091021.pdf sourced online [PowerPoint presentation]. Available at: http://www.dgnb.de (Accessed: 03 November 2009).

Ding, G. (2008). Sustainable Construction - The role of Environmental Assessment Tools. *Journal of Environmental Management* 86, pp.451-464.

Dixon, N. (2000). *Common Knowledge: How Companies thrive by sharing what they know.* Boston, Mass.: Harvard Business School Press

Dixon, T., Colantonio, A. and Shiers, D. (2008). A green profession? A global survey of RICS members and their engagement with sustainability agenda. *Journal of Property Investment & Finance* 26 (6), pp.460-481.

Dixon, T., Keeping, M., and Roberts, C. (2008). Facing the Future: Energy Performance Certificates and Commercial Property. *Journal of Property Investment & Finance* 26 (1), pp.96-100.

Dixon, T. (2009). *Sustainability and Corporate Real Estate. Property in the Economy.* RICS.

Dixon, T. *et al.* (2009). Is there a demand for sustainable office? An analysis of UK business occupier moves (2006-2008). *Journal of Property Research* 26 (1), pp.61-85.

Dugard, S. (2007). *Green Looks Up - Around the world, office towers are rising up as powerful new symbols of responsibility.* Office Property 2007. Cushman & Wakefield.

Durkheim, E. (1983). *Pragmatism and Sociology.* Cambridge University Press.

Egbu, C. (2004). Managing Knowledge and Intellectual Capital for improved Organizational Innovations in the Construction Industry: An Examination of Critical Success Factors. *Construction and Architectural Management* 11 (5), pp.301-315.

Elkington, J. (1998). *Cannibals with Forks. The Triple Bottom Line of the 21st Century.* Oxford: Capstone Publishing.

Ellison, L. and Brown, P. (2011). Sustainability Metrics for Commercial Real Estate Assets - Establishing a Common Approach. *Journal of European Real Estate Research* 4 (2), pp.113-130.

Ellison, L. and Sayce, S. (2007). Assessing Sustainability in the existing Commercial Property Stock. *Property Management* 25 (3), pp.287-304.

El-Tayeh, A. (2008). *Social web-based Systems for supporting geographically dispersed Project Teams in the Architecture - Engineering – Construction Industry.* PhD thesis. Manchester Business School.

Engelhardt, A. (2010). Her mit den Assets, die sich lohnen. *Immobilien Zeitung*, 30 September.

EPBD (2008). *Implementation of the Energy Performance of Buildings Directive Country Reports 2008.* European Commission Directorate General for Energy and Transport.

Erenz, B. (2013). Ein Wort geht um die Welt. *Die Zeit* 18 April.

Ermine, J.-L., Boughzala, I. and Tounkara, T. (2006). Critical Knowledge Map as a Decision Tool for Knowledge Transfer Actions. *The Electronic Journal of Knowledge Management* 4 (2), pp.129-140.

Fernie, S. *et al.* (2003). Knowledge Sharing: Context, Confusion and Controversy. *International Journal of Project Management* (21), pp.177-187.

Fong, P. (2003). Knowledge Creation in multidisciplinary Project Teams: An Empirical Study of the Processes and their dynamic Interrelationships. *International Journal of Project Management* (21), pp.479–486.

Fowler, F. (2009). *Survey Research Methods.* Applied Social Research Methods Series. Thousand Oaks: SAGE.

Freeman, L. (2004). *The Development of Social Network Analysis: A Study in the Sociology of Science.* BookSurge, LLC.

Fuerst, F. and McAllister, P. (2010). *What is the Effect of eco-labelling on Office Occupancy Rates in the USA?* RICS, Fibre Series.

Galbraith, K. (2008). Debating the Green Building Premium. The New York Times Green Inc. 20 November. [Online]. (Accessed 02 March 2010).

Gerber, R. (1998). How do workers learn their Work? *The Learning Organization* 5 (4), pp.168-175.

Gertis, K. *et al.* (2008). Was bedeuted "Platin"? Zur Entwicklung von Nachhaltigkeitsbewertungsverfahren. *Bauphysik* 30 (4), pp.244-256.

Gluch, P., Johansson, K. and Räisänen, C. (2012). Knowledge Sharing and Learning across Community Boundaries in an Arena for Energy Efficient Buildings. *Journal of Cleaner Production*, pp.1-9.

Granovetter, M. and Swedberg, R. (2001). *The sociology of economic life.* 2nd edition ed. Oxford: Westview Press.

Granovetter, M. (1973). The Strength of Weak Ties. *American Journal of Sociology* 78 (6), pp.1360-1380.

Grant, R. (1996). The Resource-Based Theory of the Competitive Advantage: Implication for Strategy Formulation. *California Management Review* 34 (Spring), pp.114-135.

Graubner, C.-A. and Lützkendorf, T. (2008). Bewertung und Zertifizierung der Nachhaltigkeit von Gebäuden. *Mauerwerk* 12 (2), pp.53-60.

Häkkinen, T. and Belloni, K. (2011). Barriers and Drivers for Sustainable Building. *Building Research & Information* 39 (3), pp.239-255.

Haldin-Herrgard, T. (2000). Difficulties in Diffusion of tacit Knowledge in Organizations. *Journal of Intellectual Capital* 1 (4), pp.357-365.

Halliday, S. (2008). *Sustainable Construction.* Butterworth-Heinemann.

Hanneman, R. and Riddle, M. (2005). *Introduction to Social Network Methods.* University of California [Online] (Accessed 10 April 2012).

Hansen, M. (2002). Knowledge Networks: Explaining Effective Knowledge Sharing in Multiunit Companies. *Organization Science* 13 (3), pp.232-248.

Harkness, J. (2008). Comparative Survey Research: Goals and Challenges. In: de Leeuw, E., Hox, J., Dillman, D. (ed.) *International Handbook of Survey Methodology.* New York, London: Taylor & Francis Group.

Hastings, C. (1996). *The New Organization - Growing the Culture of Organisational Networking.* London: McGraw-Hill.

Hegner, H.-D. (2008). Neue Herausforderungen für Nachhaltigkeit und Energieeffizienz. *Mauerwerk* 12 (2).

Hill, S. and Lorenz, D. (2011). Rethinking Professionalism: Guardianship of Land and Resources. *Building Research & Information* 39 (3), pp.314-319.

Hinge, A., Taneja, O. and Bobker, M. (2008). Sustainability in Commercial Buildings - Bridging the Gap from Design to Operations. *Green Building Insider* 23.

Hinnels, M. *et al.* (2008). The greening of commercial leases. *Journal of Property Investment & Finance* 26 (6), pp.541-551.

Hofstede, G. (1994). *Cultures and Organizations. Software of the Mind*. McGraw-Hill, London.

Huang, J. and Newell, S. (2003). Knowledge Integration Processes and Dynamics within the Context of cross-functional Projects. *International Journal of Project Management* (21), pp.167-176.

Hunter, K. and Kelly, J. (2008). Grounded Theory. In: Knight, A., Ruddock, L. (ed.) *Advanced Research Methods in the Built Environment.* Wiley-Blackwell.

Inkpen, A. and Tsang, E. (2005). Social Capital, Networks, and Knowledge Transfer. *Academy of Management Review* 30 (1), pp.146-165.

Ives, W. *et al.* (1998). Knowledge Management: An Emerging Discipline with a Long History. *Journal of Knowledge Management* 1 (4), pp.269-274.

Jaeger, F. and Hunziker, C. (2009). DGNB Seal of Quality - Sustainable in every respect. *Detail.*

Kamara, J. *et al.* (2002). Knowledge Management in the Architecture, Engineering and Construction Industry. *Construction Innovation* (2), pp.53-67.

Katzung, N. (2011). Investoren setzen auf Öko-Immobilien. *Immobilien-Zeitung,* 31 January.

Kauntze, R. (2007). *The green block.* Available at: http://www.cnbcmagazine.com story/the-green-block/223/1/ (Accessed: 24.02.2010).

Keeping, M. (2000). *The Cutting Edge 2000 - What about demand? Do investors want 'sustainable buildings'?* RICS.

Keeping, M. and Rawstron, M. (2010). *From Green to Gold 2010 - Key Findings. The big questions about sustainable investment attitudes.* Research Bulletin. London: GVA Grimley.

Knight, A. and Ruddock, L. (2008). *Advanced Research Methods in the Built Environment.* Oxford : Wiley-Blackwell.

Kurul, E., Colantonio, A., Otsuka, N. (2006). Influences of Social Capital on Knowledge Creation. *World Conference on Accelerating Excellence in the Built Environment.* Birmingham, UK, 2-4 October 2006.

Kurul, E., Colantonio, A., Otsuka, N. (2007). Knowledge Creation and Absorptive Capacity: Influences of Social Capital. *CIB 2007 World Congress*. South Africa.

Kurul, E., Tah, J., Cheung, F. (2011). Does the UK Built Environment Sector have the Institutional Capacity to deliver Sustainability? *Architectural Engineering and Design Management* 8 (1), pp.42-54.

Lange, O. (2012). 1. Fortbildungsveranstaltung FKT zum Thema nachhaltiger Krankenhausbau. In: Drees and Sommer, eds. Hamburg.

Lorenz, D. and Lützkendorf, T. (2011). Sustainability and Property Valuation. *Journal of Property Investment & Finance* 29 (6), pp.644-676.

Lu, S.-L. and Sexton, M. (2007). *Drinking at the Knowledge ba: Innovation in small construction knowledge intensive professional Service Firms.* FiBRE Findings in Built and Rural Environments. RICS.

Lützkendorf, T. (2007). *Schwarze Zahlen mit „green buildings“ – Energieeffizienz und Umweltqualität von Immobilien als Voraussetzung für deren Wertstabilität und Wertentwicklung?* Karlsruher Transfer, Universität Karlsruhe.

Lynn, P. (2008). The Problem of Nonresponse. In: De Leeuw, E., Hox, J., Dillman, D. (ed.) *International Handbook of Survey Methodology.* New York, London: Taylor & Francis Group.

McDermid, D. I. (2006). Pragmatism. Available at: http://www.iep.utm.edu/pragmati/ (Accessed: 20 July 2007).

McDermott, R. (1999). Why Information Technology inspired but cannot deliver Knowledge Management. *California Management Review* 41 (4), pp.103-117.

McDermott, R. and Archibald, D. (2010). Harnessing your Staff's Informal Networks. *Harvard Business Review*.

McIntosh, A. (2011). *European Property Sustainability Matters: Delivering a Sustainable Future.* King Sturge, UK.

Melles, G. (2008). New Pragmatism and the Vocabulary and Metaphors of Scholarly Design Research. *MIT Design Issues*.

Moreland, R. and Myaskovsky, L. (2000). Exploring the Performance Benefits of Group Training: Transactive Memory or Improved Communication? *Organizational Behaviour and Human Decision Processes* 82 (1), pp.117-133.

Morgan, D. (1997). *Focus Groups as qualitative Research.* 2nd ed. London, Thousand Oaks, New Delhi: Sage.

Müller, B. (2011). Die Schönheit des Waldbaus. *Süddeutsche Zeitung,* 20 June 2011.

Müller-Prothmann, T. (2007). Social Network Analysis: A Practical Method to Improve Knowledge Sharing. In: Kazi, A., Wohlfahrt, L., Wolf, P. (ed.) *Hands-On Knowledge Co-Creation and Sharing; Practical Methods and Techniques.* Stuttgart: Knowledge Board, pp.219-233.

Myers, D. (2008). *Construction Economics - A New Approach.* London and New York: Taylor & Francis.

Nahapiet, J. and Ghoshal, S. (1998). Social Capital, Intellectual Capital, and the Organizational Advantage. *Academy of Management Review* 23 (2), pp.242-266.

Nahser, F. (1997). *Learning to Read the Signs – Reclaiming Pragmatism in Business.* Butterworth-Heinemann.

Naoum, S. (2006). *Dissertation Research and Writing for Construction Students.* Oxford Elsevier Butterworth-Heinemann.

Nardi, P. (2006). *Doing Survey Research. A Guide to Quantitative Methods.* Boston: Pearson/ Allyn & Bacon.

Nelson, A. (2007). The Greening of U.S. Investment Real Estate – Market Fundamentals, Prospects and Opportunities. RREEF Research.

Nelson, A. (2008). *Globalization and Global Trends in Green Real Estate Investment.* RREEF Research.

Nelson, A. (2009). *How Green a Recession? - Sustainability Prospects in the US Real Estate Industry.* RREEF Research.

Nelson, A. (2012). *Building Labels vs. Environmental Performance Metrics: Measuring what's important about Building Sustainability.* RREEF Research.

Nonaka, I. (1991). The Knowledge-Creating Company. *Harvard Business Review* 69 (6), pp.96-104.

Ormerod, R. (2006). The History and Ideas of Pragmatism. *Journal of the Operational Research Society* 57, pp.892 - 909.

Pink, M. (2011). *Nachhaltige Büroimmobilien.* Hamburg: Savills Research Germany.

Pitt, M. *et al.* (2009). Towards Sustainable Construction: Promotion and Best Practices. *Construction Innovation* 9 (2), pp.201-224.

Pivo, G. (2008). Responsible Property Investing: What the Leaders are doing. *Journal of Property Investment & Finance* 26 (6), pp.562-576.

Porritt, J. (2011). *The Greenest Government Ever: One Year On*. A report to Friends of the Earth.

Portes, A. (1998). Social Capital: Its Origins and Applications in Modern Sociology. *Annual Review of Sociology* 24, pp.1-24.

Pryke, S. (2008). Social Network Analysis. In: Knight, A., Ruddock, L. (ed.) *Advanced Research Methods in the Built Environment*. Wiley-Blackwell.

Ragsdell, G. (2009). Participatory Action Research: A winning Strategy for Knowledge Management. *Journal of Knowledge Management* 13 (6), pp.564-576.

Reagans, R. and McEvily, B. (2003). Network Structure and Knowledge Transfer: The Effects of Cohesion and Range. *Administrative Science Quarterly* 48 (2), pp.240-267.

RICS (2012). *Going for Green: Sustainable Building Certification Statistics Europe*. RICS, Sustainability.

Riege, A. (2005). Three-dozen knowledge-sharing Barriers Managers must consider. *Journal of Knowledge Management* 9 (3), pp.18-35.

Robinson, M. (2008). *Breaking the "Vicious Circle of Blame".* Prime Property Award Union Investment, pp.76-79.

Rodrigues, L., Garratt, T. and Ebbs, N. (2012). Is added Sustainability equal added Value? *Energy Conversion and Management* 63, pp.203-207.

Rohrbacher, H. (2001). Managing the Technological Transition to Sustainable Construction of Buildings: A Socio-Technical Perspective. *Technology Analysis & Strategic Management* 13 (1), pp.137-150.

Rosenthal, E. (1997). Social Networks and Team Performance. *Team performance management* 3 (4), pp.288-294.

Roy, M., Parent, R. and Desmarais, L. (2003). Knowledge Networking: A Strategy to Improve Workplace Health & Safety Knowledge Transfer. *Electronic Journal of Knowledge Management* 1 (2), pp.159-166.

Ruddy, T. (2000). Taking Knowledge from Heads and putting it into Hands. *Knowledge and Process Management* 7 (1), pp.37-40.

Rydin, Y., Amjad, U. and Whitaker, M. (2007). Environmentally Sustainable Construction: Knowledge and Learning in London Planning Departments. *Planning Theory & Practice* 8 (3), pp.363-380.

Saunders, T. (2008). *A Discussion Document comparing International Environmental Assessment Methods for Buildings*. BRE Global.

Schmidt, M. (2013). Ach, Bologna! *Die Zeit,* 18 April 2013, p.85.

Schröpfer, V., Kurul, E. and Tah, J. (2011). Knowledge Transfer in Construction Project Teams delivering Sustainable Office Buildings in the UK and Germany. *Sixth International Conference on Construction in the 21st Century (CITC-VI) 'Construction Challenges in the New Decade'.* Kuala Lumpur, Malaysia.

Schröpfer, V., Kurul, E. and Tah, J. (2013). Knowledge Transfer in Project Teams delivering Office Buildings to Sustainable Building Standards. *Sustainable Building and Construction Conference.* Coventry, UK.

Schwarz, N. *et al.* (2008). The Psychology of Asking Questions. In: de Leeuw, E., Hox, J., Dillman, D. (ed.) *International Handbook of Survey Methodology.* New York, London: Taylor & Francis Group.

Schweber, L. (2013). The effect of BREEAM on Clients and Construction Professionals. *Building Research & Information* 41 (2), pp.129-145.

Scott, J. (2000). *Social Network Analysis - A Handbook.* 2nd ed. Published London: SAGE.

Seufert, A., von Krogh, G. and Bach, A. (1999). Towards Knowledge Networking. *Journal of Knowledge Management* 3 (3), pp.180-190.

Sharkie, R. (2003). Knowledge Creation and its Place in the Development of Sustainable Competitive Advantage. *Journal of Knowledge Management* 7 (1), pp.20-31.

Siemieniuch, C. and Sinclair, M. A. (1999). Organisational Aspects of Knowledge Lifecycle Management in Manufacturing. *International Journal of Human-Computer Studies* (51), pp.517-547.

Smith, G. (2009). Social Networking and the Transfer of Knowledge. *The Electronic Journal of Knowledge Management* 7 (1), pp.165-178.

Smith, P. (2006). *The Green Wave is coming*. In: Cushman and Wakefield, Office edition.

Snowden, D. (2003). The Knowledge you need, right when you need it. *Knowledge Management Review* 5 (6).

Spinks, M. (2011). Adoption of a Network Approach to Sustainable Building Standard Process, not Product: A Response Column to “A political-ecology of the Built Environment: LEED Certification for Green Buildings”, Cidell, 2009, Local Environment, 14(7), pp. 621–633. Local Environment: *The International Journal of Justice and Sustainability* 16 (1), pp.87-92.

Spradley, J. (1980). *Participant Observation.* Orlando: Harcourt Brace Jovanovich College Publishers.

Steedman, H. (2011). *Apprenticeship Policy in England: Increasing Skills versus boosting young People's Job Prospects.* Centre for Economic Performance, CEP Policy Analysis.

Stevenson, F. and Bordass, W. (2011). *Even Bad News Can Be Beneficial, Interview with Fionn Stevenson and Bill Bordass about housing post-occupancy evaluation.* D&A.

Sun, P. and Scott, J. (2005). An Investigation of Barriers to Knowledge Transfer. *Journal of Knowledge Management* 9 (2), pp.75-90.

Swedberg, R. and Granovetter, M. (2001). Introduction to the second edition. In: Granovetter, M., Swedberg, R. (ed.) *The sociology of economic life.* Oxford: Westview Press.

Thomson, C., El-Haram, M. and Emmanuel, R. (2010). Mapping Knowledge Flow during Sustainability Assessment. *Proceedings of the Institution of Civil Engineers Urban Design and Planning* 163 (DP2), pp.67-78.

Tiwana, A. (2000). *The knowledge management toolkit: practical techniques for building a knowledge management* system. Upper Saddle River: Prentice-Hall.

Ugwu, O. (2005). A service-oriented framework for sustainability appraisal and knowledge management. *ITcon* 10, pp.245-263.

Uzzi, B. (2001). Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. In: Granovetter, M., Swedberg, R. (ed.) *The sociology of economic life.* 2nd edition Oxford: Westview Press, pp.207-240.

Van Wijk, R., Jansen, J. and Lyles, M. (2008). Inter- and Intra-Organizational Knowledge Transfer: A Meta-Analytic Review and Assessment of its Antecedents and Consequences. *Journal of Management Studies* 45 (4), pp.830-853.

Von Weizsäcker, E. (2005). Buildings Technology in the Vanguard of Eco-efficiency. *The 2005 World Sustainable Building Conference.* Tokyo, Japan.

Wallbank, C. and Price, B. (2007). *Sustainability: Bridging the Knowledge Gap.* Jones Lang LaSalle, Australia.

Wasserman, S. and Faust, K. (2009). *Social Network Analysis: Methods and Applications.* Cambridge: Cambridge University Press.

WBCSD (2007). *Energy Efficiency in Buildings. Business Realities and Opportunities.* World Business Council for Sustainable Development.

WBCSD (2008). *Energy Efficiency in Buildings. Business Realities and Opportunities.* World Business Council for Sustainable Development.

WBCSD (2009). *Energy Efficiency in Buildings. Transforming the Market.* World Business Council for Sustainable Development.

WBCSD (2012). *Energy Efficiency in Buildings 2.0. Action on Energy in Buildings.* World Business Council for Sustainable Development.

Wegner, D., Raymond, P. and Erber, R. (1991). Transactive Memory in Close Relationships. *Journal of Personality and Social Psychology* 61 (6), pp.923-929.

Wilkesmann, U., Fischer, H. and Wilkesmann, M. (2009). Cultural Characteristics of Knowledge Transfer. *Journal of Knowledge Management* 13 (6), pp.464-477.

Williams, K. and Dair, C. (2007). What is stopping Sustainable Building in England? Barriers experienced by Stakeholders in Delivering Sustainable Developments. *Sustainable Development* 15: 135–147.

Yin, R. (1994). *Case Study Research.* 2nd edition. London: SAGE.

Yin, R. (2014). *Case Study Research.* 5th edition. London: SAGE.

Yudelson, J. (2008). *The Business Case for Green Buildings.* Prime Property Award Union Investment, pp.88-91.

Zhou, S., Siu, F. and Wang, M. (2009). Effects of Social Tie Content on Knowledge Transfer. *Journal of Knowledge Management* 14 (3), pp.449-463.

APPENDICES

Appendix A – Participant Information Sheet

Participant Information Sheet May 2012

OXFORD BROOKES UNIVERSITY

Knowledge transfer in project teams delivering office buildings to sustainable building standards

You are being invited to take part in a research study. Before you decide to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and ask, if anything is unclear or if you need further information.

What is the purpose of the study?
This research project aims to understand knowledge transfer in project teams, delivering office buildings to sustainable building certificate standards. The focus is hereby on finding out how the different project participants receive this specialized knowledge from each other, and accordingly determine ways of enhancing this knowledge transfer.

Why have I been invited to participate?
This construction project has been chosen, because it is a new office construction aiming for a sustainability certificate (BREEAM). The researcher will visit construction site and hand out questionnaires to be completed ideally by all project participants. This should take no longer than 40 minutes each and should not interfere with the work flow. In addition the researcher would like to take pictures of construction details and revise project documentation, e.g. drawings.

Do I have to take part and what should I do if I want to take part?
After handing you this information sheet the researcher will return 48 hrs later and ask you if you would like to participate in this study. Your cooperation and involvement in this study is completely voluntary and you are free to withdraw at any time without giving a reason, even if you have decided to take part initially there will be no consequences on your behalf. If you decide to withdraw during the research, any unprocessed data that has been collected from you till then, will be deleted. It would be much appreciated if you could give an early notice if you decide either to opt-in or to opt-out from this research to the principal investigator via email: **vschroepfer@brookes.ac.uk**

Will what I say in this study be kept confidential and what will happen to the results of the research study?
Collected data will remain entirely confidential and anonymous, and will be used for academic purposes only. The data generated in the course of the research will be retained in accordance with the University's policy of Academic Integrity and will be kept securely in paper and electronic form for a period of ten years after the completion of the research project. All electronic data collected in the field will be stored on a security –code encrypted lap-top and memory stick to comply with the Data Protection Act. Some de-identified data may have to be released, if anyone makes a Freedom of Information request under EPSRC guideline.
The results of this research will appear mainly in the thesis submitted for the degree of Doctor of Philosophy in Real Estate and Construction. Part of the research will also be published in journals and conference papers. If you would like to receive a summary report of the results of this research project please let the researcher know.

Who is organising and funding the research?
The researcher is conducting this research as a PhD student at Oxford Brookes University, Department of Real Estate and Construction, Oxford, United Kingdom. She is supervised by Prof Joseph Tah and Dr Esra Kurul at Oxford Brookes University. This research study is funded by the Department of Real Estate and Construction, Oxford Brookes University, and the Engineering and Physical Sciences Research Council (EPSRC). If you have any questions please do not hesitate to contact us.

EPSRC
Engineering and Physical Sciences Research Council

Page 2 Participant Information Sheet

Contact for Further Information

Veronika Schröpfer	Prof Joseph Tah	Dr Esra Kurul
PhD Researcher	Director of Studies	Supervisor
vschroepfer@brookes.ac.uk	jtah@brookes.ac.uk	ekurul@brookes.ac.uk
Tel: +44 (0) 7909 014948	Tel: +44 (0) 1865 483482	Tel: +44 (0) 1865 483482

Oxford Brookes University, Department of Real Estate and Construction, Gipsy Lane, Headington, Oxford, OX3 OBP, UK

Who has reviewed the study?
The research has been approved by the University Research Ethics Committee, Oxford Brookes University. If you have are any concerns about the way in which the study has been conducted, please contact the Chair of the University Research Ethics Committee at Oxford Brookes University: **ethics@brookes.ac.uk**

Thank you very much for taking time to read this information sheet!

Appendix B – Consent Form

CONSENT FORM

OXFORD BROOKES UNIVERSITY

Full title of Project: Knowledge transfer in project teams delivering office buildings to sustainable building standards

Name, position and contact address of Researcher:

Name:	Veronika Schröpfer
Position:	Research student
Address:	Department of Real Estate and Construction, School of the Built Environment, Oxford Brookes University, Headington Campus, Gipsy Lane, OX3 0BP, Oxford, UK
Mobile:	07909 014948
E-mail:	vschroepfer@brookes.ac.uk

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason. ☐
3. I agree to take part in the above study. ☐

Please tick box

		Yes	**No**
4.	I agree to the use of anonymised quotes in publications.	☐	☐
5.	I agree that my data gathered in this study may be stored (after it has been anonymised) in a specialist data centre for 10 years and may be used for future research.	☐	☐

Name of Participant	Date	Signature
Veronika Schröpfer		
Name of Researcher	Date	Signature

Appendix C – Questionnaire

Knowledge transfer in project teams delivering office buildings to sustainable building standards

This questionnaire is part of a research project that aims to understand knowledge transfer in project teams delivering new office buildings to sustainable building certificate standards. The focus is on finding out how different project participants receive expert knowledge on how to build sustainably from each other, and determining ways of enhancing this transfer of knowledge.

This construction project has been chosen because it is a new office construction aiming for a sustainability certificate (BREEAM).

Please see the participant information sheet provided to you by the researcher for more information and feel free to contact the researcher if you have further questions.

Please read the following instructions carefully

This questionnaire will take about 40 minutes to complete. We would like you to find a time when you are less likely to be disturbed, and to answer all the questions in one session if possible.

Please return this questionnaire with your response, even if you are unable to answer all questions. Your participation is very important for this research and your cooperation is very much appreciated.

Your answers will be kept strictly confidential and anonymous, and will be used for academic purposes only. No names mentioned in the questionnaire will be disclosed to your employer or any other third party. Should you have any enquiries, please do not hesitate to contact us via email at: vschroepfer@brookes.ac.uk.

We would like to thank you for taking the time to participate in this research.

Contact for further information and returning the filled in questionnaire:

Oxford Brookes University
Department of Real Estate and Construction
Veronika Schröpfer
Headington Campus
Gipsy Lane
Oxford OX3 0BP

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Sponsors: EPSRC Engineering and Physical Sciences Research Council

In cooperation with: Oxford Brookes University

Questionnaire

Knowledge transfer in project teams delivering office buildings to sustainable building standards

1. First and Last Name: ………………………………………..

2. Age group: 16-24 25-34 35-44 45-54 55-64 +65

3. Gender: Male Female

4. Nationality: ………………………………….

5. Which company do you work for?

6. Please describe briefly your job role and responsibilities in your company in general and this project in particular:

7. For how long have you been working in this company and this position?

   ………. years in company ………. years in position

8. Who do you report to during this project and how often?

9. What is your educational/ job training background (i.e. apprenticeship)?

10. Are you aware that this construction project is aiming for a sustainability certificate – BREEAM?

    Yes No

11. Did you have a special training regarding sustainable construction?

    Yes No

12. Could you please describe further why you have/ have not had a special training, and if you had one, what kind of training was it:

Please continue overleaf if necessary.

13. Does your company use particular types of 'green' / sustainable materials or technologies?

Yes No N/A

14. Could you please describe further why you ticked 'yes' or 'no'? If you ticked 'yes' could you please describe further what types of materials/ technologies your company uses and how you did you become aware of it?

15. Do these new materials and technologies require special building techniques/ skills that you needed to learn?

Yes No N/A

16. Could you please describe further, why you need or don't need any special skills? And if you need special skills, what kind of skills are these, and how did you learn/ acquire these skills? E.g. training on the job, retraining (by whom?), hands-on workshops etc. And in which way do you apply these skills now to your workaday life?

Please continue overleaf if necessary.

NEW SECTION: PLEASE ANSWER THE FOLLOWING QUESTIONS WITH REGARD TO **ADVICE YOU SEEK** OF OTHERS ON BUILDING SUSTAINABLY WITHIN THIS PROJECT

17. **Within your immediate team and with other companies participating on this project:**
    If you need advice about anything related to building sustainably, **who do you go to** for advice and how often? (1= Less than once a week, 2= Once a week, 3= More than once a week, 4= Once a day, 5= More than once a day).

    Could you please indicate, how long such a conversation is on average and describe, if there is any reason why you ask especially this person.

    Please also describe in which relation this person stands to you, e.g. working colleague, boss or supervisor (please indicate if the person is a close friend or relative as well as a colleague)

    Could you also please indicate which subject areas you discuss most with this person: sustainable building materials, technologies or techniques.

    If you **do not communicate** with others on this project please indicate this here and feel free to comment:

Who (first and last name)	Company they work for	How often?					Time in Min	Why do you go to this person?	Your relation to this person	**Subject discussed: Sustainable** Materials Technologies Techniques
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				

18. Which of the following methods do you use to get the advice described in the previous question (no. 17)?

Please tick **all** methods. If you find one is missing just write it below.

Please also tick how often you use each method (1= Less than once a week, 2= Once a week, 3= More than once a week, 4= Once a day, 5= More than once a day) and rank them regarding their importance to you, in order to get this special knowledge.

Please also name the person you prefer to use each method with.

x	**Way of communication**	**How often?**					**Rank order**	**Who (first and last name)**
	Phone	1	2	3	4	5		
	E-mail	1	2	3	4	5		
	Team-Meeting	1	2	3	4	5		
	Direct conversation	1	2	3	4	5		
	Networking/ Socialising	1	2	3	4	5		
	Online Networks	1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		

19. Which of the following methods are used to give you the advice described in the previous question (no. 17)?

Please tick **all** methods. If you find one is missing just write it below.

Please also tick how often you use each method (1= Less than once a week, 2= Once a week, 3= More than once a week, 4= Once a day, 5= More than once a day) and rank them regarding their importance to you, in order to get this special knowledge.

Please also name your colleagues - who explains the knowledge to you using which method?

x	**Way of communication**	**How often?**					**Rank order**	**Who (first and last name)**
	Phone	1	2	3	4	5		
	E-mail	1	2	3	4	5		
	Team-Meeting	1	2	3	4	5		
	Direct conversation	1	2	3	4	5		
	Networking/ Socialising	1	2	3	4	5		
	Online networking	1	2	3	4	5		
	Direct Demonstration	1	2	3	4	5		
	To point something out on drawings	1	2	3	4	5		
	To point something out using the internet	1	2	3	4	5		
	To point something out on the company's intranet	1	2	3	4	5		
	To point something out in a report	1	2	3	4	5		
	To point something out in a book or instructions manual	1	2	3	4	5		
	Mentoring/ contact person with more work experience	1	2	3	4	5		
	Apprenticeship	1	2	3	4	5		
	Vocational Training/ School	1	2	3	4	5		
	Adult Learning/ Training on the Job	1	2	3	4	5		
	Routines/ Repetition	1	2	3	4	5		
	Post-Project Reviews	1	2	3	4	5		
	Co-Location of Staff / Assigning Knowledge Workers	1	2	3	4	5		
	Using BIM	1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		

NEW SECTION: PLEASE ANSWER THE FOLLOWING QUESTIONS WITH REGARD TO **ADVICE YOU MIGHT GIVE** OTHERS ON BUILDING SUSTAINABLY WITHIN THIS PROJECT

20. **Within your immediate team and with other companies participating on this project: Which colleagues** on this project ask you for advice about anything related to building sustainably, and how often? (1= Less than once a week, 2= Once a week, 3= More than once a week, 4= Once a day, 5= More than once a day).

Could you please indicate how long such a conversation is on average?

Please also describe in which relation this person is to you, e.g. working colleague, boss or supervisor (please indicate if the person is a close friend or relative as well as a colleague)

Could you also please indicate which subject areas this person wants to discuss with you mostly: sustainable building materials, technologies or techniques?

If you **do not communicate** with other companies on this project please indicate this here and feel free to comment:

Who (first and last name)	Company they work for	How often?					Time in Min	Why do you go to this person?	Your relation to this person	**Subject discussed: Sustainable** Materials Technologies Techniques
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				
		1	2	3	4	5				

21. Which of the following methods do <u>other project participants use</u> to get the advice from you described in the previous question (no. 20)?

Please tick **<u>all</u>** methods used. If you find one is missing just write it below.

Please also tick how often they use each method (1= Less than once a week, 2= Once a week, 3= More than once a week, 4= Once a day, 5= More than once a day) and rank them regarding, which one is best for you.

Please also name them- who prefers to ask you using which method?

x	**Way of communication**	**How often?**					**Rank order**	**Who (first and last name)**
	Phone	1	2	3	4	5		
	E-mail	1	2	3	4	5		
	Team-Meeting	1	2	3	4	5		
	Direct conversation	1	2	3	4	5		
	Networking/ Socialising	1	2	3	4	5		
	Online Networks	1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		

22. Which of the following methods <u>do you use</u> to give your colleagues the advice described in the previous question (no. 20)?

Please tick **<u>all</u>** methods used. If you find one is missing just write it below.

Please also tick how often they use each method (1= Less than once a week, 2= Once a week, 3= More than once a week, 4= Once a day, 5= More than once a day) and rank them, regarding which one is best for you.

Please also name them- who do you explain things using which method?

x	**Way of communication**	**How often?**					**Rank order**	**Who (first and last name)**
	Phone	1	2	3	4	5		
	E-mail	1	2	3	4	5		
	Team-Meeting	1	2	3	4	5		
	Direct conversation	1	2	3	4	5		
	Networking/ Socialising	1	2	3	4	5		
	Online networking	1	2	3	4	5		
	Direct Demonstration	1	2	3	4	5		
	To point something out on drawings	1	2	3	4	5		
	To point something out using the internet	1	2	3	4	5		
	To point something out on the company's intranet	1	2	3	4	5		
	To point something out in a report	1	2	3	4	5		
	To point something out in a book or instructions manual	1	2	3	4	5		
	Mentoring/ contact person with more work experience	1	2	3	4	5		
	Apprenticeship	1	2	3	4	5		
	Vocational Training/ School	1	2	3	4	5		
	Adult Learning/ Training on the Job	1	2	3	4	5		
	Routines/ Repetition	1	2	3	4	5		
	Post-Project Reviews	1	2	3	4	5		
	Co-Location of Staff / Assigning Knowledge Workers	1	2	3	4	5		
	Using BIM	1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		
		1	2	3	4	5		

23. When you think about the transfer of knowledge on how to build sustainable during this project - what do you think went particularly well and what went wrong? And why? Do you have any suggestions on how to improve the knowledge transfer?

24. Any other comments?

THANK YOU VERY MUCH FOR YOUR PARTICIPATION!

Appendix D – Case Study UK1: Closeness and Eigenvector Centrality Results

ID	Closeness
Mec3	16002
Mec1	15876
Mec6	15876
FA2	15626
FA3	15626
FA4	15626
FA1	15624
CC2	15251
CC3	15251
CC4	15251
CC5	15251
CC6	15251
CC7	15251
CC1	15246
Soc3	2470
Soc4	2381
FO5	2374
FO6	2374
BMS11	2366
BMS12	2366
Elec6	2366
BW5	2363
BW1	2360
BW4	2360
BW2	2359
FO7	2354
FO8	2354
DL7	2330
MC9	2330
Soc1	2330
Soc2	2330
DL6	2329
Dev1	2316
Elec9	2316
SE2	2316
SE3	2316
SE4	2316
SE5	2316
SE6	2316
SE7	2316
SE8	2316
Log2	2312
ST7	2312
Elec7	2309
Arc4	2309
Arc5	2309
Arc6	2309
Arc10	2309
Arc11	2309
Arc12	2309
Arc9	2309
Arc3	2303
Arc7	2303
Str1	2298
Arc8	2297
MC4	2290
Mec12	2279
Mec13	2279

ID	Eigenvector
CM5	0.451
Elec4	0.366
CM1	0.292
BMS2	0.28
BMS1	0.265
DL1	0.202
MC2	0.187
ST1	0.185
Elec3	0.164
Elec5	0.164
MC1	0.156
ST3	0.135
Elec8	0.122
Mec5	0.116
BMS5	0.113
BMS6	0.113
Mec4	0.109
Elec1	0.109
Mec2	0.108
CM7	0.107
BMS3	0.098
BMS4	0.095
Log1	0.088
CM2	0.087
FO3	0.083
Elec2	0.083
ST2	0.075
CM4	0.075
Arc1	0.073
SE1	0.062
Arc2	0.062
CM3	0.056
CM6	0.051
BMS10	0.049
BMS9	0.049
DL3	0.048
DL2	0.047
ST4	0.046
BMS7	0.046
BMS8	0.046
ST8	0.037
MC3	0.036
DL4	0.035
DL5	0.035
FS1	0.033
MC5	0.033
MC6	0.033
MC7	0.033
MC8	0.033
FO2	0.032
ST5	0.032
ST6	0.032
FO4	0.028
MC4	0.027
FS2	0.025
Mec10	0.025
Mec9	0.025
Arc3	0.024