Schropfer, V., Tah, J. and Kurul, E. (2017) 'Mapping the knowledge flow in sustainable construction project teams using social network analysis', *Engineering, Construction and Architectural Management*, 24 (2), pp. 229-259.

DOI: https://doi.org/10.1108/ECAM-08-2015-0124

MAPPING THE KNOWLEDGE FLOW IN SUSTAINABLE CONSTRUCTION PROJECT TEAMS USING SOCIAL NETWORK ANALYSIS

Structured Abstract

Purpose of this paper	Knowledge transfer (KT) practices in five construction projects delivering sustainable office buildings in Germany and the UK are examined using Social Network Analysis (SNA).
Design/methodology/approach	Case studies were adopted as research strategy, with one construction project representing one case study. A combination of quantitative data, social network data and some qualitative data on perceptions of the sustainable construction process and its KT were collected through questionnaires. The data was analysed using a combination of descriptive statistics, cross tabulations, content analysis and SNA. This resulted in a KT map of each sustainable construction project.
Findings	The findings resulted in a better understanding of how knowledge on sustainable construction is transferred and adopted. They show that large amounts of tacit knowledge were transferred through strong ties in sparse networks.
Research limitations/implications	The findings could offer a solution to secure a certain standard of sustainable building quality through improved KT. The findings indicate a need for further research and discussion on network density, tie strength and tacit KT.
What is original/value of paper	This paper contributes to the literature on KT from a social network perspective. It combines the concepts of network structure and relatedness in tie contents regarding specialised knowledge, i.e. sustainable construction knowledge. Thereby it provides a robust approach to mapping knowledge flows in office building projects that aim to achieve high levels of sustainability standards.

Keywords: social network analysis, knowledge transfer, sustainable construction, sustainable office buildings, performance gap

1 INTRODUCTION

Sustainability caused a paradigm change in construction industry (Rohrbacher, 2001). 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 changing nature of technical knowledge required. Some sustainable buildings require high-tech components, which are supplied by specialized companies, e.g. renewable energy solutions. Hence, 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 and Dair, 2007). Yet, 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). 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. Moreover a better co-operation and integration of various stakeholders is required from project inception to completion (Rohrbacher, 2001; Williams and Dair, 2007).

Sustainable construction faces many problems with one of them being the so-called performance gap. 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 and Leaman, 2013). 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 and Price, 2007). Additionally sustainability issues render this even more challenging, as they change the nature of the required knowledge and result in the need for knowledge on additional aspects of design and construction. The performance gap could be interpreted as an indication, that knowledge transfer (KT) on how to build sustainably between all project participants involved is not yet perfect. It could thus be argued that an enhanced KT between all project participants offers a solution to achieve a certain quality of the built result.

Considerable research on the importance of social networks for knowledge sharing and creation, as well as their enhancing and inhibiting effect was carried out in the early to mid 2000s (Fong, 2003; Bresnen *et al.*, 2003). Recent related work involves the use of social network analysis in measuring and modelling safety communication in small crews in the US (Alsamadant et. al, 2013) and assessing social sustainability in construction projects (Almahmoud and Doloi, 2015). However, Bresnen *et al.* (2003) and Kurul (2013) stress that research on social mechanisms that support knowledge sharing is still limited. Inkpen and Tsang (2005) state that there is a theoretical gap in research where the key concepts of networks, social capital and organizational KT interconnect. 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, which combines concepts of network structure and relatedness in tie content regarding specialised knowledge. These suggestions were taken into account and applied to the area of sharing sustainable construction knowledge in order to make an original contribution to closing the research gap on mapping the knowledge flows in project environments.

This paper draws on a study, which investigated KT practices in construction teams delivering sustainable office buildings in Germany and the UK using a social network analysis approach. The aim is to develop a better understanding of how knowledge on sustainable construction is transferred and adopted within project teams delivering new office buildings to sustainable building standards in Germany and the UK in order to suggest ways of enhancement. Following the introduction, the paper sets the background of the study. The relation between social networks and KT is explored. The methodology is presented with one case study as a fieldwork example for illustrative purposes. This paper focuses on the SNA aspect of the study. As a result, selected findings on network structure, actor centrality, and tie contents and characteristics, as well as their relationships to each other are discussed.

2 THE PERFORMANCE GAP AND THE IMPORTANCE OF TRANSFERRING SUSTAINABLE CONSTRUCTION KNOWLEDGE

There is a very diverse range of professions within the construction sector, all carrying different kinds of knowledge that contribute to a project. The increasing importance of sustainability and the complexity it introduces to construction projects (Myers, 2008) requires better co-operation of all stakeholders through enhanced knowledge sharing from project inception to completion (Rohrbacher, 2001; Williams and Dair, 2007). However, the construction industry is a fragmented project-based sector, 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 arguably 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 innovation (Fong, 2003). Characteristics such as professional silos with their own knowledge and language render KT in project teams difficult (Bresnen et al., 2003). Furthermore, it has to be acknowledged that the various actor groups on a construction project use different tools for transferring their knowledge.

The above problems associated with transferring knowledge, assume that all stakeholders possess the knowledge on how to build sustainably. Yet, previous research argued that still only a small number of professionals in the industry possess the specialised knowledge and experience to design and operate sustainable buildings successfully (WBCSD, 2009; Kurul et al., 2011). In addition to personal know-how, personal commitment was identified as another main barrier for professionals adopting sustainable building techniques (WBCSD, 2009). This finding reflects not only a lack of training and education in relevant techniques (Dixon et al., 2008), but also a supportive environment and business acceptance to prosper personal commitment. Furthermore, there also seem to be difficulties in the process of translating this new knowledge into practice (Ugwu, 2005), i.e. how knowledge is transferred and widely adopted between professionals and operatives. This might result in a performance gap in ‘green’ buildings. Hence, these buildings could be an unproductive investment, which do not help achieving governmental targets, such as cutting down carbon emissions in the long run.

Several studies compare the actual performance of sustainable buildings with their intended one, revealing differing results (Bordass et al., 2004). Thus, 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 and Leaman, 2013). In this context Innovate UK has a £8million Building Performance Evaluation programme, which monitors the performance of 48 non-domestic projects (Palmer and Armitage, 2014). Another on-going project is the ‘Carbon Buzz’, a free UK online platform, where designers can report the predicted and actual performance of buildings in terms of energy and water consumption and embodied carbon (Stevenson and Bordass, 2011). In 2014 the European Commission issued a Horizon 2020 call on investigating and bridging the performance gap. This shows that this term is well known and the issue is currently recognised across Europe, hindering a successful implementation of sustainability principles into the built environment.

Bordass et al. (2004) argue that there are many potential reasons for the performance gap that can be assigned to four main building life-cycle phases: project inception, design development, construction and commissioning, and in-use. This paper concentrates on the the construction stage to explore how knowledge on building sustainably is transferred between all participants of a sustainable construction project, due to the significance of this transfer in the delivery of sustainable buildings. The construction process is 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 intent, the occupier has a higher chance to operate the building in a sustainable way.

3 KNOWLEDGE TRANSFER AND SOCIAL NETWORKS

Smith (2009) argues that many knowledge management problems are caused by forgetting that individuals are part of the process. Roy et al. (2003) support this view by describing that organisational KT discourse initially dealt with knowledge as an object, saw the user as a passive actor and completely ignored the context. Beherend and Erwee (2009) also identify this as one approach to managing knowledge, and propose mapping the knowledge flows between actors as another approach. They argue that possible relationships between actors and common themes, which relate to KT, e.g. boundaries, can be revealed by conducting a more holistic analysis using SNA in the latter approach.

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 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. Moreover Müller-Prothmann (2007) argues that SNA is a very effective tool for analysing KT in networks and can support it by, for example, identifying experts and discovering 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.

Previous research indicated that social networks could influence KT. 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 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. Nahapiet and Ghoshal (1998) support this by claiming that social networks are a valuable source for new knowledge through combination and exchange of knowledge. Transfers of non-material resources are frequent communications between actors, where ties represent, for example, sending or receiving messages, giving or receiving advice, or providing information (Granovetter, 1973).

Social networks are also important for team performance, because of their ability to realize creative output (Kratzer et al., 2010). The aspect of cross-functional teams is especially important in the context of the 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 (Borgatti and Cross, 2003). 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 and Cross, 2003). This is vital in a construction project, since participants are from a very diverse range of disciplines.

Given the influence of social networks on KT, various social network models and concepts combined with KT were reviewed. This review drew attention to social network characteristics that influence KT. These characteristics were categorised into the following three groups and will be discussed in detail.

1. Network Structure (e.g. Density, Connectivity, Hierarchy, Structural Holes);
2. Tie content and tie characteristics (e.g. Strength, Weakness);
3. Actor Attributes (e.g. Centrality);

3.1 NETWORK STRUCTURE

Several authors (e.g. Reagans and McEvily, 2003) declare that network structure itself affects KT. The main properties of the network structure (Hanneman and Riddle, 2005) are:

- Size, i.e. the number of nodes/ actors;
- Components, number and size of components including isolates;
- Connectivity and cut-points;
- Social cohesion, i.e. the extent to which a relationship is surrounded by strong third-party connections;
- Network Range, i.e. the extent to which network connections span institutional, organisational or social boundaries;
- Network density, i.e. the total number of links between the nodes of a network;
- Structural Holes, i.e. parts of the network, where not all possible connections are present; this is more common in larger networks and thus influenced by the size.

Network density has an obvious effect on KT, as less links, thus a lower density, may mean less KT. 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 (Hannemann and Riddle, 2005). Nonetheless, a dense network is inefficient, because it returns less diverse information for the same cost as a sparse network (Nahapiet and Ghoshal, 1998), whereas sparse networks may increase the absorptive capacity of a network. Cohen and Levinthal (1990) define ‘absorptive capacity’ as innovative capability to recognize the value of new, external information, assimilate it and apply it to commercial ends. Thus most productive teams are internally cohesive, but have external networks full of structural holes (Reagans and McEvily, 2003).

Network density also influences the type of knowledge that is transferred through it (e.g. Reagans and McEvily, 2003; Nahapiet and Ghosal, 1998). Various scholars argue that cohesive social networks facilitate the transfer of complex and tacit knowledge between individuals (Hansen, 2002; Reagans and 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.

3.2 TIE CONTENT AND TIE CHARACTERISTICS

Uzzi (2001) argues that it is not only the network structure that affects KT, but also the embeddedness of ties. Ties are the links through which KT between actors occurs. Here the quality of a tie, i.e. the relationship and how it is managed designates, for example, the access opportunities of an actor (ibid). Moreover respect, longevity of a relationship and shared professional and educational backgrounds support KT 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. Strong ties, identified by trust, lengthy time frames 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 and McEvily, 2003). Nonetheless Granovetter (1973) argues that weak ties provide access to novel information. The concept of weak ties is therefore similar to the one of structural holes (Burt, 1992; in Portes, 1998).

Often acquiring knowledge is risky, because it implies admitting incompetence and dependence. 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). Since trust develops over time, opportunities for KT between individuals should also increase over time (Inkpen and Tsang, 2005). 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’

(Wegner et al., 1991). 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.

3.3 ACTOR ATTRIBUTES

Besides general actor attributes, such as cultural background, gender, age and hierarchy (job level/ education), actor centrality can also influence KT. Centrality measures are important in order to investigate which actor is more central i.e. cross-linked than others regarding the relationship under examination (Hanneman and Riddle, 2005), in this case KT on sustainable construction.

The degree centrality measures are divided into in-degree and out-degree. The in-degree of a node, i.e. 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). Degree calculations can be used to divide actors into experts and knowledge consumers (Müller-Prothmann, 2007). The in-degree centrality value identifies experts, i.e. knowledgeable people in the area of sustainable construction. 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 never asked themselves, i.e. 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, thus are never asked. The combination of a high in- and out-degree value implies the actor to be a knowledge broker i.e. receives knowledge and forwards it, or an expert in some areas and a consumer in others. These so-called gatekeepers can also be identified by a high betweenness centrality (Freeman, 1979; in Scott, 2000). The concept is based on dependency, as other actors depend on the broker/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.

4 THE RESEARCH METHODOLOGY

Having identified the social network characteristics which influence KT, this section details the research design, data collection and analysis. Case studies were adopted as the research strategy, with one construction project representing one case study. They facilitate an in-depth exploration of a complex issue without isolating it from its context (Bryman, 2008). As such, this research follows the growing knowledge management literature where case studies have been widely adopted (Ragsdell, 2009).

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.

4.1 Sampling & case study selection

The UK and Germany were chosen as the geographical contexts of this study. They were chosen because they aimed for the same high level of sustainability and were comparable in size and have similar levels of expected construction volume of new sustainable buildings (Nelson, 2008). This research examined new construction, because it allowed for a more straightforward comparison of the levels of sustainability than refurbishment projects. This comparison was based on the established sustainability certificates, i.e. BREEAM in the UK and DGNB in Germany. Offices, which represent the largest sub-sector of commercial buildings in most countries (WBCSD, 2009), were chosen as the focus of this study. This choice was informed by the fact that commercial buildings emit similar amounts of CO2 to residential buildings, and yet, at the time, research on how to reach Government targets, e.g. on reducing carbon emissions of buildings in Germany and the UK, largely focussed on residential buildings. The focus on office buildings also ensured similarity in the scope of the projects.

First a database of the population of new office buildings which aimed for a BREEAM or DGNB certificate was created. This approach allowed for a database of projects with comparable levels of sustainability. Initially, it was intended that this database would be created using the databases of the certifying bodies in the two countries. This was possible in Germany, but not in the UK. At the time, the BRE's database of new office projects aiming for a BREEAM certificate was under construction. A list of all new office constructions in Germany with the appropriate pre-certificate was generated from the official DGNB website, including the information shown in Table 1.

The database for projects in Germany was then filtered to make sure the chosen cases followed a similar time frame in order to allow data collection during construction stage. This reduced the sample size to 29 projects. Subsequently the auditors, i.e. assessors, of these projects were invited to participate in the research. Thereafter the auditor initiated the contact with the developer or owner, who gave their consent or not. This process resulted in the three German projects participating in this study.

In the UK, a list of target developers and assessors was drawn from the trade journals and the press. Their appropriate projects were included in the database. Relevant professionals involved in these projects were invited to take part in the research. This resulted in the two UK case studies.

Table 1 summarises the key facts of all five case studies conducted in this study.

Table 1: Key Facts of Case Studies

	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	Ca. 51,097	3,692 sqm	22,710 sqm	19,817 sqm

	sqm	sqm			
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

Once the case studies were confirmed, random sampling was used to identify the survey respondents (Fowler, 2009). The researcher visited the construction site and randomly handed out questionnaires to the participants on-site during the visit. Naturally, the quality and quantity of the data collected in each 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.

4.2 Data Collection

Surveys were the main data collection tool for this research. They are the most commonly used tool to collect social network data (Wassermann and Faust, 2009). They also have practical advantages such as the speed of data collection (Nardi, 2006). It could also be argued that the outcome is more reliable than qualitative methods because of the standardised way of asking questions (Nardi, 2006; Schwarz *et al.,* 2008).

The questionnaire, which is included in the Annex, is divided into three main sections. The first section elicited data on 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 sustainably (Q10-16).

The second part (Q17 and Q20) of the questionnaire was designed to collect social network data for use in mapping the knowledge flow in the construction project. This set of questions was designed in the format of a free recall with a free choice. Hence, respondents were rather asked to name those people with whom they shared/transferred knowledge on how to build sustainably, instead of being offered a fixed roster with names to tick. This approach allowed the participants to name as many people as they like. Thus, participants had more freedom in their replies (Wasserman and Faust, 2009). The data yielded a multi-relational data-set, as the relationship to the other actors was also investigated. In addition to this, some data on tie characteristics was collected using a frequency matrix, which showed, on a Likert scale, how often respondents asked or advised that person. Further information on tie content was collected by asking respondents which subject area they are most likely to discuss with this person, i.e. sustainable materials, technologies, techniques or any combination of these. As a result, the data collected was very rich in terms of revealing various social network and KT characteristics.

The third section of the questionnaire was designed to collect 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, and given using a different one.

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

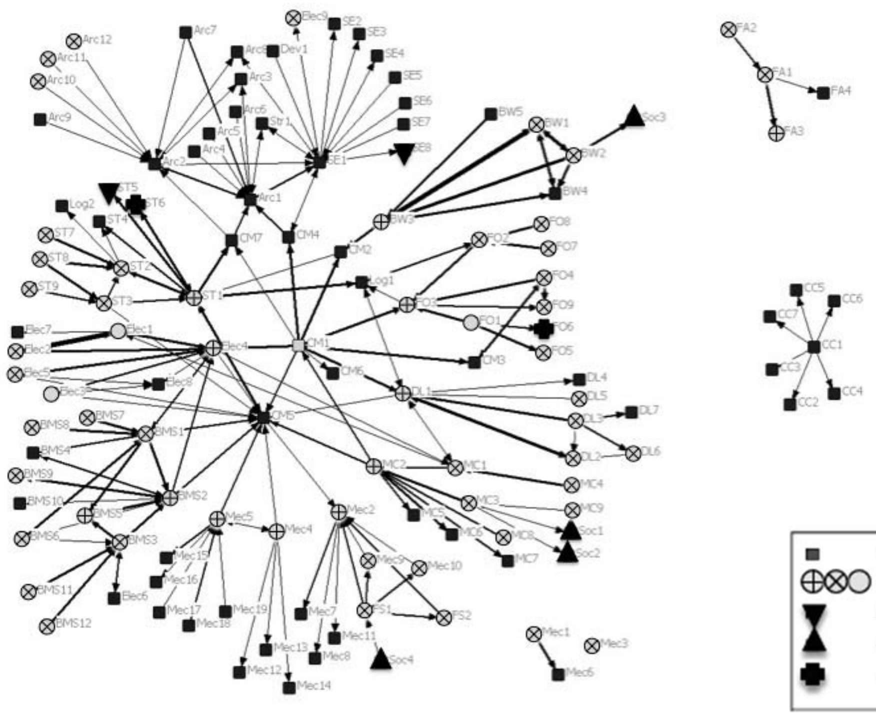
The data was analysed using a combination of descriptive statistics, cross tabulations, content analysis and SNA, which is the focus of this paper.

4.3 Social Network Analysis

The network structure, which in this case represents a knowledge flow map, can be shown using a sociogram. A matrix describing the relationships between various actors can be converted into such a graph (Scott, 2000) by using software packages for social network analysis (i.e. UCINET) and visualisation (i.e. Netdraw) (Borgatti et al., 2002). Such a knowledge map provides further insight into the knowledge sources, flows, constraints and sinks (Liebowitz, 2005).

UCINET is a software package that includes the formulae to calculate the metrics. It is available online and can be used by readers who would like to replicate the study. The formulae which underpin the UCINET calculations should be available from the developers (Borgatti et al., 2002).

An example of a knowledge map of one of the five case studies is depicted in Figure 1 for illustrative purposes and for the sake of brevity. Case study UK1 is a prime office scheme located in central London and a speculative development carried out by a main contractor. It is a mixed-use scheme including prime office, residential and retail uses. The total gross area is approximately 80,000 square meters. The project received a BREEAM Excellent Office certificate in 2006. The site visit was conducted in December 2011 and a total of 39 questionnaires were completed.



Construction Manager	CM
Dry Lining	DL
Metall Ceilings	MC
Building Management Services	BMS
Fire Alarms	FA
Brickwork	BW
Mechanical Contractors	Mec
Electrical Contractors	Elec
Fire Stopping Contractors	FS
Stonework	St
Commercial joinery fit-out	FO
Architect	Arc
Services Engineer	SE
Structural Engineer	Str
Cost Consultant	CC
Logistics	Log
Developer	Dev
Contacts outside the project	Soc

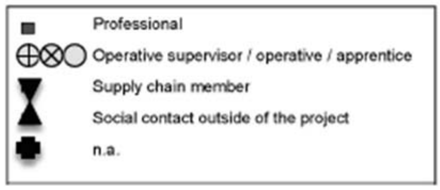


Figure 1: Knowledge Transfer Network of Case Study UK1

Each icon on the network symbolizes one actor, i.e. one construction project participant. They are rendered according to the job level, e.g. professionals. This grouping was considered appropriate as KT in construction projects is widely assumed to be top-down according to hierarchy levels (e.g. Ugwu, 2005). The codes denote the company each actor works for, e.g. CM1-7 are all working for the construction management company. The weight of the links between the actors represents the frequency of the KT between two nodes. The more often they have exchanged knowledge on sustainable construction the thicker the line, i.e. the stronger the tie (Hannemann and Riddle, 2005). The link direction is from the recipient to the knowledge source, i.e. who asks whom.

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 1. The main component includes the following companies: construction management, dry-lining, metal ceilings, building management systems, brickwork, mechanical contractors, electrical contractors, fire alarm 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. They link most of the other companies. Each of the three small components represent 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. This is to say 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.

Three M&E contractors are left out of their team, which can be seen at the lower part of Figure 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.

5 FINDINGS

5.1 NETWORK STRUCTURE

Table 2 summarises the key results of the five case studies in terms of network structure, i.e. network size, density and standard deviation. For the sake of brevity this will be explained with the example of case study UK1. The size of this network is 125 nodes, made up of 39 research participants and 86 other project participants named by them. The network density, as described in section 3.1, is 0.0320 with a standard deviation of 0.3480, i.e. 3% of all possible ties are present in this network. 3% 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 the ties (Hannemann and Riddle, 2005), i.e. in this case the frequency of KT.

Table 2: Network structure of the case studies

	UK		Germany		
	UK1	UK2	GE1	GE2	GE3
Network Size	125	39	38	50	35
Network Density	0.0320	0.0628	0.0532	0.0559	0.0899
Standard Deviation	0.3480	0.4402	0.3811	0.4254	0.5880

All five case studies showed very sparse networks. According to the literature, explicit knowledge should be effectively communicated in sparse networks made up of weak ties and structural holes (e.g. Reagans and McEvily, 2003; Nahapiet and Ghosal, 1998). Fernie et al. (2003) support this view by stating that weak ties seem to limit the exchange of tacit knowledge. Further exploration of the tie contents in Section 5.4 will investigate whether this relation between network density and tie content was the case in this study.

5.2 ACTOR CENTRALITY

Actor centrality measures, both degree and betweenness, 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 established in order to retrieve more information on the strength of the tie.

Table 3 provides an example of in degree and out degree values as well as the betweenness values of five actors of case study UK1. For the sake of brevity these values cannot be presented for all actors of all case studies, though Table 4 summarizes the analysed results.

The project manager (CM5) has the highest betweeness centrality score. This result illustrates that he/she is regarded as an expert not only on sustainable construction, but an over-all person to contact with any queries, as it would have been 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, who occupy the last two positions on the betweeness centrality scores, 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, when looking at their responses to Q10-16.

The knowledge consumers are only operatives and one intern. Nonetheless this shows that the operatives might be unaware of the sustainability goal but do request knowledge on sustainable construction. Hence this might suggest better communication regarding sustainable construction down to operative levels.

Table 3: Actor Centrality Measures in Case Study UK1

Actor	In Degree	Actor	Out Degree	Actor	Betweenness
Elec4	26	ST1	30	CM5	2952.347
BMS2	24	CM1	29	CM1	2669.559
CM5	24	BW1	20	ST1	1072.805
BW3	22	BW2	20	CM4	1029.405
BMS1	21	BMS1	18	SE1	1026.952

As presented in Table 4 colleagues/peers were overall the most frequently consulted knowledge sources 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 construction materials. Nonetheless DGNB contacts and colleagues/peers 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/peer that they work together on a daily basis, though still someone from the same company. In case study UK2 the colleague/peer asked was mostly the sustainability manager employed by the construction management company. He/she was considered as an expert and hence number one knowledge source for most project participants.

Table 4: The knowledge sources in the case studies

	UK		Germany		
	UK1	UK2	GE1	GE2	GE3
Knowledge Sources	Colleague/ Peer Manager	Colleague/ Peer	Supply chain member DGNB	Colleague/ Peer Supervisor/	Supervisor/ Manager Colleague on another

	Colleague from another company Supervisor		contact Colleague/ Peer Client	Manager Colleague from another company	sustainable project

It was argued that indicating the knowledge source also indicates to a certain extent of trust, as by asking for advice the actor admits being less knowledgeable in the subject area (Borgatti and Cross, 2003). Hence it might not be surprising that peers are chosen over managers and supervisors in four case studies. There might be more trust-based relations amongst peers, than with someone from a superior job level. Moreover peers 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 and 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 and Vendelø, 1999). This will be further explored in Section 5.4.

In addition, 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 being a knowledge source or consumer. It can be argued that 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.

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 the 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 better employ a sustainability manager. In case studies UK2 and GE3 this was done by the construction management company.

5.3 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). 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 sustainable construction knowledge.

The results showed a difference in KT methods used to request and to transfer/ receive knowledge.

In all five case studies the most used KT methods were the phone, direct conversation, emails and team meetings. These methods are used to transfer tacit knowledge (Haldin-Herrgard, 2000; Egbu, 2004). Thus, the selection of KT methods provides further evidence for the transferred knowledge types.

It is quite possible that the methods of data transfer may have changed since December 2011 when the UK1 case study data was collected. However, one of the key findings of this research is that, in the main, tacit knowledge is transferred, and that knowledge transfer methods, which rely on human interaction are preferred. The authors accept that there may have been changes to the preferred data transfer methods, given the advent of mobile technologies in the intervening years. However, the fundamentals of the discourse on tacit knowledge and its transfer have remained largely unchanged since Polanyi introduced these concepts in 1958. Hence, where tacit knowledge transfer is concerned, we do not expect that the current situation is much different from that in 2011.

Another interesting finding is that it is of no importance whether the actor is an expert, gatekeeper or knowledge consumer, they all seem to prefer the same methods to transfer sustainable construction knowledge. As a result one could argue that the chosen methods are not linked to actor centrality in any case study.

Furthermore the results in all five case studies showed that different age groups preferred different KT methods. Figure 2 presents these results for case study UK1. 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, when comparing the results of all five case studies, it was not possible to identify a trend, e.g. younger participants prefer on-line methods, in terms of the methods preferred by different age groups. These preferences differ from case study to case study. It is therefore not possible to determine specific preferred methods by age group.

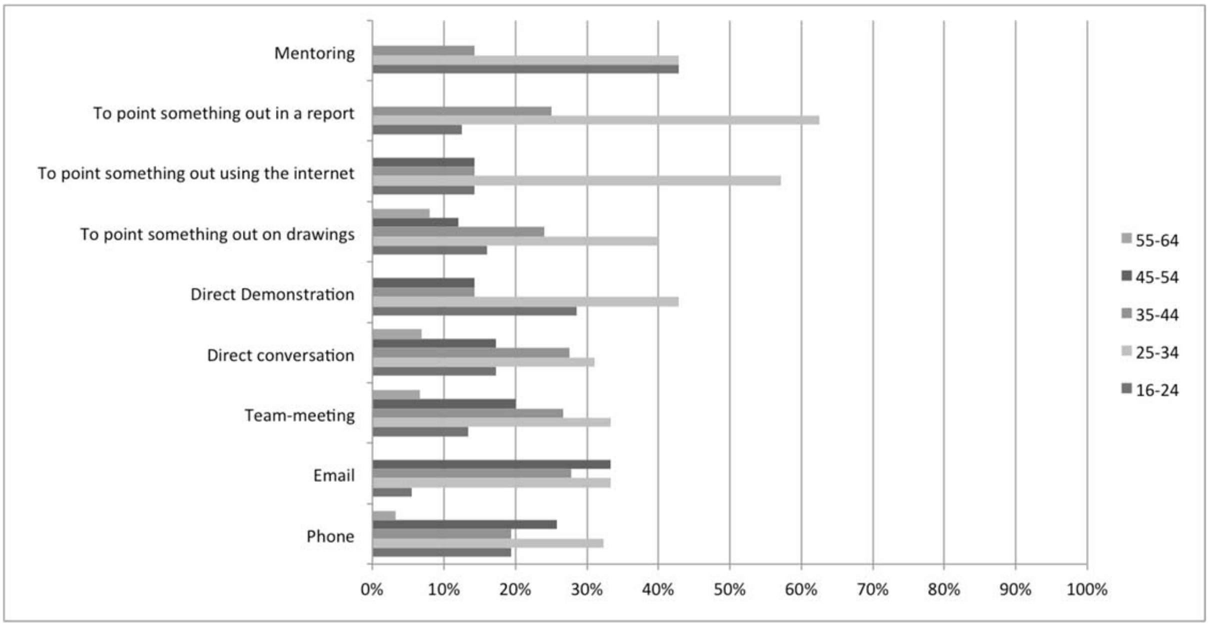


Figure 2: Knowledge transfer methods cross tabulation with age groups in case study UK1

A link between job level and choice of KT methods could however be established in three case studies, i.e. UK1, GE2 and GE3. Literature asserts an influence of job level on 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). Thus the findings add to these discussions as they show that additionally job level affects KT in terms of the different KT method preferences.

5.4 TIE CONTENT

Different types of knowledge to be found in literature were 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 most required by the KT participants, which gave further indications of the knowledge types transferred. The results summarised in Table 5 show a variation for the most requested knowledge areas in the five case studies.

Table 5: Transferred knowledge in the case studies

	UK	Germany

	UK1	UK2	GE1	GE2	GE3
Most discussed subject areas	Materials (21.6%) and a combination of all three subject areas (21.6%)	A combination of all three subject areas (43.14%)	Materials (39.02%)	A combination of all three subject areas (32.77%)	Materials (27.27%) Techniques (27.27%) A combination of all three subject areas (22.72%)
Tacit knowledge part	55.2%	58.82%	39.01%	55.18%	65.89%

As depicted in Table 5, '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.

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. 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 line with the findings of case studies UK1, GE1 and GE3. However, the new knowledge on techniques was defined as purely tacit. Table 5 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 at transferring tacit knowledge.

The large amount of transferred tacit knowledge through the sparse networks is a notable 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). 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 shows a need for more research on the relationship of network density, tie strength and tacit KT.

6 CONCLUSION

There is an increasing perceived value and thus need for sustainable buildings worldwide. However, one of the main barriers towards delivering sustainable construction can be found in the transfer of knowledge on how to build sustainably. This paper suggests that enhancing this special KT between all project participants could help in the long run to secure a certain standard of green building quality. A research project investigating KT practices of construction project teams delivering office buildings to sustainable building standards (BREEAM and DGNB) in Germany and the UK forms the basis of this paper.

This paper aims at developing a robust approach to mapping knowledge flows in project teams that are delivering office buildings to sustainability standards. This approach is illustrated by using, mainly, the SNA results on case study UK1. As such, this paper does not aim at providing a comparison of knowledge flow networks in the UK and Germany.Its key output is a robust approach to mapping knowledge flow in sustainable construction project teams. In doing so, it responds to the gap in existing knowledge in terms of combining concepts of network structure and relatedness in tie contents when specialised knowledge is exchanged (Seufert *et al.*, 1999; Hansen, 2002; Bresnen *et al.*, 2003; Inkpen and Tsang, 2005).

The following conclusions can be drawn from the analysis of the network maps presented in this paper. The network densities of all five case studies in the two countries are all relatively low, showing sparse networks regarding KT on sustainable construction. 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 aand Vendelø (1999) that strong ties are needed to facilitate tacit KT. On the other hand, the results show that strong ties do not necessarily equate to 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.

Betweeness centrality results from UK1 point to a relationship between out-degree centrality and job level; and in-degree centrality and possession of specialist knowledge of sustainable technologies. Corresponding metrics in the remaining four case studies, which can be found in Schröpfer (2014), corroborate this finding. It could have implications for communication lines for this type of projects where specialist knowledge should take precedence over job level in terms of knowledge provision.

The preferred knowledge source in four case studies is a colleague/peer. The resultant ties are likely to represent strong trust-based relationships, which are needed to transfer the knowledge requested on sustainable construction. Additionally, literature on KT methods for transferring tacit knowledge was confirmed by the results (Haldin-Herrgard, 2000; Egbu, 2004), as most methods were used to transfer large amounts of tacit knowledge. Moreover, the results showed a difference in KT methods used to request and to transfer/ receive knowledge and also regarding age and job level of the actor. Furthermore, the findings of this research confirm literature (Thomson *et al*, 2010), which suggests employing a sustainability manager as a key contact and to enhance KT on sustainable construction as a gatekeeper.

The sampling strategy, i.e. random sampling, could have been one limitation of this research in terms of biasing the results, as the quality and quantity of the data collected in each case study very much depended on the stage the construction project was in at the time of data collection. Yet, there is no statistical evidence of how well or poorly the sample represents the population, if the respondent availability affects the chances of selection (Fowler, 2009).

Further research recommendations include strengthening the overall research design by conducting follow-up interviews with the knowledge experts and consumers identified through SNA to provide deeper insights into the matter, e.g. further explanations for network positions or more suggestions to enhance the mapped KT. 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. Knowledge flow maps could also help identify the reasons behind performance gap, which is an under-researched area despite the growing body of literature on the presence of performance gap.

REFERENCES

Almahmoud, E. and Doloi, H.K. (2015) "Assessment of social sustainability in construction projects using social network analysis", Facilities, Vol. 33 Iss: 3/4, pp.152 – 176.

Alsamadant, R., Hallowell, M. and Javernick-Will, A.N. (2013), Measuring and modelling safety communication in small crews in the US using social network analysis, Construction Management and Economics, Vol. 31, No. 6, pp. 568-579.

Augier, M. and Vendelø, M. T. (1999). Networks, Cognition and Management of tacit knowledge. Journal of Knowledge Management 3 (4), pp.252-261.

Behrend, F.D. and Erwee, R. (2009), Mapping knowledge flows in virtual teams with SNA, Journal of Knowledge Management, Vol. 13, Iss. 4, pp. 99-114.

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.

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.

Bryman, A. (2008). Social Research Methods. 2nd edition. Oxford: Oxford University Press.

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.

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.

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.

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.

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.

Haldin-Herrgard, T. (2000). Difficulties in Diffusion of tacit Knowledge in Organizations. Journal of Intellectual Capital 1 (4), pp.357-365.

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.

Inkpen, A. and Tsang, E. (2005). Social Capital, Networks, and Knowledge Transfer. Academy of Management Review 30 (1), pp.146-165.

Kamara, J. et al. (2002). Knowledge Management in the Architecture, Engineering and Construction Industry. Construction Innovation (2), pp.53-67.

Kratzer, J., Leenders, R. Th. A. J, Van Engelen, J. M. L. (2010), The social network among engineering design teams and their creativity: A case study among teams in two product development programs, International Journal of Project Management, Vol. 28, pp. 428-436

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.

Kurul, E. (2013). Influences of social capital on knowledge creation: An exploration in the UK built environement sector, Architectural Engineering and Design Management, published online on 10 June 2013.

Liebowitz, J. (2005), Linking social network analysis with the analytic hierarchy process for knowledge mapping in organizations, Journal of Knowledge Management, Vol. 9, Iss. 1, pp. 76-86.

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.

Nardi, P. (2006). Doing Survey Research. A Guide to Quantitative Methods. Boston: Pearson/ Allyn & Bacon.

Nelson, A. (2008). Globalization and Global Trends in Green Real Estate Investment. RREEF Research.

Palmer, J. and Armitage, P. (2014). Innovate UK Building Performance Evaluation Programme: Early Findings from Non-Domestic Projects. Report December 2014.

Michael Polanyi (1958). Personal Knowledge. Chicago, University of Chicago Press.

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.

Riege, A. (2005). Three-dozen knowledge-sharing Barriers Managers must consider. Journal of Knowledge Management 9 (3), pp.18-35.

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.

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.

Scott, J. (2000). Social Network Analysis - A Handbook. 2nd ed. Published London: SAGE.

Schröpfer, V. (2014). Social network analysis of knowledge transfer in sustainable office building projects in the UK and Germany. PhD Thesis. Oxford Brookes University.

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.

Seufert, A., von Krogh, G. and Bach, A. (1999). Towards Knowledge Networking. Journal of Knowledge Management 3 (3), pp.180-190.

Smith, G. (2009). Social Networking and the Transfer of Knowledge. The Electronic Journal of Knowledge Management 7 (1), pp.165-178.

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.

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.

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.

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.

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 (2009). Energy Efficiency in Buildings. Transforming the Market. 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.

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.