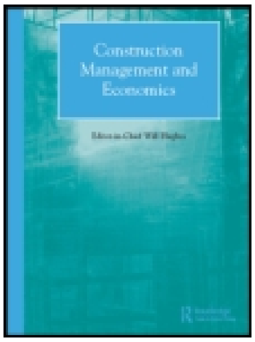

Construction Management and Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

Actors and objects: a socio-technical networks approach to technology uptake in the construction sector

Libby Schweber & Chris Harty

To cite this article: Libby Schweber & Chris Harty (2010) Actors and objects: a socio-technical networks approach to technology uptake in the construction sector, Construction Management and Economics, 28:6, 657-674, DOI: 10.1080/01446191003702468

To link to this article: https://doi.org/10.1080/01446191003702468

Published online: 18 Aug 2010.

Construction Management and Economics (June 2010) **28**, 657–674

Actors and objects: a socio-technical networks approach to technology uptake in the construction sector

LIBBY SCHWEBER and CHRIS HARTY*

School of Construction Management and Engineering, University of Reading, Whiteknights, PO Box 219, Reading RG6 6AW, UK

Received 13 February 2009; accepted 15 February 2010

We explore the contribution of socio-technical networks approaches to construction management research. These approaches are distinctive for their analysis of actors and objects as mutually constituted within socio-technical networks. They raise questions about the ways in which the content, meaning and use of technology is negotiated in practice, how particular technical configurations are elaborated in response to specific problems and why certain paths or solutions are adopted rather than others. We illustrate this general approach with three case studies: a historical study of the development of reinforced concrete in France, the UK and the US, the recent introduction of 3D-CAD software into four firms and an analysis of the uptake of environmental assessment technologies in the UK since 1990. In each we draw out the ways in which various technologies shaped and were shaped by different socio-technical networks. We conclude with a reflection on the contributions of socio-technical network analysis for more general issues including the study of innovation and analyses of context and power.

Keywords: Socio-technical systems, socio-technical networks, CM research, methodology, practice, 3D CAD, reinforced concrete, environmental assessment systems.

Introduction

The development, implementation and use of technologies are of central concern to many construction management (CM) scholars and industry practitioners. Whether investigating increases in efficiency, the integration of construction work, the dissemination of innovations, improvements in building performance or sustainability, technological artefacts have a key role to play. At the same time, dominant understandings of reform and innovation have undergone a major transformation. Whereas policy documents initially focused on the need for technical innovation and new management tools, they increasingly underline the role of culture and the obstacles that 'mind-sets' pose to reform. This shift can be seen in discussions ranging from whole life value to sustainable procurement. In each case, policy-makers and analysts posit a radical distinction between the technical, the social and the cultural, privileging one at the expense of the others in their explanatory frame.

The adoption of such a radical distinction poses a number of obstacles to understanding the uptake and ongoing development of new technologies. On the one hand, a primarily technical focus neglects the ways in which meanings and uses are inscribed into technologies. On the other hand, a primarily social focus tends to treat social problems as cultural or linguistic issues, thereby neglecting the way in which institutions and material technologies shape symbolic formulations. Both approaches neglect the effect of power on technological development.

In this paper we present three cases which treat the technological and social as mutually constituted within socio-technical networks. The aim is to delineate the types of insights which this approach offers for research into the built environment. The paper begins with a brief discussion of one version of this approach, namely the social construction of technology (SCOT). The discussion focuses on those concepts which we find to be most relevant for research into the development and use of construction technologies. This is followed by three case studies which illustrate the types of insights which this approach brings to the study of construction objects.

*Author for correspondence. E-mail: c.f.harty@reading.ac.uk

Construction Management and Economics
ISSN 0144-6193 print/ISSN 1466-433X online © 2010 Taylor & Francis
http://www.informaworld.com
DOI: 10.1080/01446191003702468

The cases include reinforced concrete, 3D-CAD systems and BREEAM. Taken together, they span the different types of objects with which actors in the construction industry engage on a daily basis, ranging from material to social technologies. The paper concludes with a more general discussion of the contribution of this approach to substantive and theoretical issues in construction research.

Methods

Before proceeding it is important to say a few words about the epistemological status of socio-technical network analysis and the three case studies. Socio-technical networks are an analytic tool or method, rather than a full-fledged theory. They can and have been developed to explore a range of different research questions, addressed at different levels of aggregation, in conjunction with different theories and explanatory frameworks. Distinguishing features include a focus on the interactions between social and material entities, and the practices through which they are developed and mobilized. In contrast to other approaches to the study of innovation, socio-technical network analyses do not treat knowledge and knowledge transfer as a separate variable or factor, governed by different principles from those guiding social actors. Instead, the approach underlines the extent to which knowledge is embedded in both objects—through the directives for action with which they are associated—and actors—through the meanings and expectations which they hold of objects.

The case studies which follow illustrate the potential contribution of this type of approach. More specifically, the cases focus on the uptake of new technologies at the project and firm level and the socio-technical networks which support—and transform—objects in use. Each case explores a different type of object.

The case of reinforced concrete examines a material or physical artefact. The discussion is organized around the by-now classic historical question of how to explain the delay in uptake in the UK, relative to the Continent and the US. The analysis rests on secondary sources, but uses a socio-technical networks approach to suggest a somewhat different answer from those usually provided.

The case of 3D-CAD systems exemplifies a virtual technology, situated somewhere between material and social artefacts. The discussion examines the introduction of a new type of virtual technology into the everyday work of four construction firms. The case draws on a larger ethnographic study of the development, implementation and use of new design tools in construction (Harty, 2005, 2008).

The discussion of environmental assessment methods is the most speculative of the three. The case was chosen to illustrate the extension of socio-technical network analysis to social, rather than material, technologies and to problems of policy uptake. The analysis rests on accounts of use in the professional media and policy documents, along with a review of the secondary literature. As in the first two cases, the aim of the discussion is to indicate the types of processes and findings which a socio-technical analysis of the tool might reveal.

Science and technology studies

The sociology of technology can be traced back to intellectual developments in the 1980s and more specifically to the extension of research questions and approaches from the sociology of science to technology. Historians and economists had already begun exploring the effect of organizational factors on technological development, thus moving research beyond technological determinism (Trist and Bamfort, 1951; Rosenberg, 1971, 1976; Chandler, 1977). Sociologists brought to the table an interest in the social, political and cultural dimensions of technological innovation and diffusion (Pinch and Bijker, 1984; Bijker, 2000). This, combined with an increasing interest in the social and political implications of new technologies and risks associated with nuclear and large-scale industrial technologies, helped to establish the sociology of technology as a recognized and vibrant field of inquiry (Hess, 1995; Jasanoff *et al.*, 1995; Bijker *et al.*, 1999; Bijker and Law, 2000). Socio-technical network approaches represent an important stream within this literature.

The social construction of technology (SCOT)

The case for the role of social logics in the invention and development of new technologies is perhaps most strongly made by proponents of the social construction of technology (SCOT). Studies in SCOT tend to begin from a particular object, such as reinforced concrete, 3D-CAD systems or BREEAM. The approach focuses on the way in which social groups influence technological development. Central analytic concepts include *relevant social groups*, *technological frames*, *interpretive flexibility* and *stabilization* or *closure*.

The term *relevant social group* refers to those actors who actively influence the ongoing development of the artefact in question. The term can be used to refer to organized or unorganized groups of individuals; it is sometimes extended to institutions and organizations, such as the military or a particular industrial firm. As Pinch and Bijker explain: 'all members of a certain social group share the same set of meanings, attached to a specific artifact' (1984, p. 414). This set of shared understandings is referred to as a *technological frame*. 'Like a Kuhnian paradigm, it may include goals, key problems, current theories, rules of thumb, testing procedures and exemplary artefacts that tacitly or explicitly structure group members' thinking, problem solving, strategy formation and design activities' (Bijker cited in Klein and Kleinman, 2002, p. 31).

The complexity and dynamics of technology development are grounded in these different technological frames and the conflicts which ensue when actors with different visions and interests attempt to influence the ongoing development of an artefact. In terms of a research agenda, the approach focuses attention on the interests and expectations which different actors have of the object in question and the way in which they shape either the technical development of the artefact or its use in a particular setting. As the discussion of 3D-CAD systems which follows indicates, different firms adopt and adapt formally similar tools for very different ends. These differing ideas about what an object is or should be illustrate the *interpretive flexibility* (Bijker, 1995; Bijker and Law, 2000) of the artefact. In order to produce a stable artefact, negotiations over its content need to be closed down, *interpretive flexibility* must be reduced and some type of consensus achieved.

Stabilization or *closure* is achieved when problems are redefined in such a way as to incorporate different concerns into a single (loosely) shared frame. For example, reinforced concrete was adopted in the US as a structural material when both industry and university-based material scientists agreed on a particular set of practices and institutionalized them in a new set of formal standards and new workplace hierarchies (see below). However, *closure* is never final and technological frames can be transformed; new *relevant social groups* can emerge and bring with them new problems and challenges.

For a more structuralist analysis

In the past few years, socio-technical network analyses have expanded in a number of directions. Two, which seem to us to be particularly relevant for this paper, concern the broader institutional conditions in which networks develop and the study of social technologies.

The case for a more structural approach has recently been outlined by Klein and Kleinman (2002). While SCOT signals the importance of broader social and technical factors in shaping the dynamics of micro-level negotiation around the meaning and use of artefacts, most scholars focus their empirical work on the problems of *interpretive flexibility* and *closure*. Missing from their analyses is an explanation of why certain groups managed to impose their vision on the ongoing development of a particular technology and why others found their concerns excluded. By paying more attention to the institutional conditions under which these negotiations develop, scholars will be in a stronger position to move from analyses of *how* to explanations of *why* particular technologies assumed a particular form at a particular moment in time, and with what effect. Such factors include differences in relevant groups' capacities or power, institutionalized rules of access and exclusion, resource accessibility and the role of both the state and financial institutions to change the parameters of the debate.

A second key development is the shift from material to social technologies. In his analysis of the Deltaplan, Bijker identifies two types of technology: physical or hardware technology and social technologies. In this case, physical technologies include the fascine mattresses used to build dikes and clay and sand structures used to withstand specific forces. Relevant social technologies include: traditional dike management systems, combining physical artefacts with measuring equipment, surveillance procedures and management schemes (Bijker, 1995).

As this depiction indicates, the term 'social technology' includes the range of management tools designed to shape human behaviour. By referring to these tools as social technologies, the researcher focuses attention on the way in which particular *scripts* are embedded in material representations, be it a handbook or piece of software. This move, in turn, opens the way to ask about the development, interpretation, use and resilience of these tools. A central concept here concerns the *social embeddedness* of such objects or the strength of the socio-technical networks in which they are situated.

Mobilizing a socio-technical networks analysis

As this brief discussion indicates, SCOT suggests a distinctive programme of research. First it points to the need to identify—rather than assume—the relevant actors involved in the development and diffusion of a particular technology. Secondly, it calls attention to the range of different interpretations at play in the ongoing deployment of that artefact. It asks: What interests and issues are the objects seen to address? What features are consequently valued? And what criteria are consequently evoked in assessing them? Thirdly, it calls for inquiry into the historical processes by which certain features and uses come to be adopted and others neglected. Finally, calls for the integration of SCOT with the study of institutional contexts draw attention to the way in which certain uses, understandings and criteria of evaluation come to be privileged and to the conditions supporting one outcome over another. Attention is also drawn to the social consequences of stabilization and thereby to the co-production of objects and society through the elaboration of socio-technical networks.

The discussions that follow draw on this research agenda to consider the development, implementation and use of three construction technologies. The cases are at different stages of research and have been condensed for the purposes of this article. Our hope is to use them to demonstrate the potential contribution of socio-technical network analysis to research on the construction industry.

Case 1: Uptake and stabilization: reinforced concrete in France, the UK and the US

Our first example concerns the introduction of reinforced concrete into the construction industry in the early decades of the 20th century. The case study explores the contribution of SCOT to the uptake of a material technology in different national institutional contexts. The discussion focuses on the process of stabilization or closure by which a particular socio-technical network crystallizes around a physical artefact and secures a particular use, set of meanings and characteristics. The analysis provides an opportunity to extend the method from a single local case study to national comparisons. It also illustrates the way in which socio-technical network analyses treat the problem of knowledge transmission by documenting the infusion of knowledge across the network.

The analysis begins from the question of how to explain differences in the timing and uptake of reinforced concrete in three distinct cases, namely France (and the Continent more generally), the UK and the US. The discussion rests on a number of secondary sources. While none of these studies adopts a socio-technical networks approach, many of them document the invention, uptake and diffusion of this new material. As such they can be used to sketch out the types of relationships that such a study might reveal. Before entering into the analysis, it is helpful to highlight a few characteristics of reinforced concrete which are relevant for the discussion.

The term 'reinforced concrete' refers to the introduction of metal reinforcement into concrete forms. While the idea of mixing cement with aggregates and water can be traced back to Roman times, a series of innovations in the last decades of the 19th century transformed it into a commercially viable, scientifically based building material (Hamilton, 1956). The aim was to produce a material that exhibited the properties of tensile strength, fire resistance, waterproofing and versatility. Our focus here is on *the changing composition of reinforced concrete* and its adoption as a structural material, which could substitute for timber, masonry, wrought iron or steel.

One of the distinctive features of reinforced concrete involved its reliance on formal or scientific knowledge, along with practical know-how (Simonnet, 2001). As such, its development marked the introduction of science into commercial practice, with far-reaching consequences for the distribution of expertise and the social division of labour, both on site and between internal stakeholders.

The development of Continental systems

The commercialization of reinforced concrete began on the Continent. More specifically, it originated in France and rapidly spread to other European countries, most notably Germany. At the heart of these early developments was a series of legal arrangements which allowed inventors to patent entire building systems, rather than just techniques or products, and to grant exclusive licences for their use in particular areas. In the 1870s a number of inventors took out patents for the use of reinforced concrete as a structural material (Baker, 1956; Bussell, 2001; Simonnet, 2001). Although they were not the first to 'invent' the material, they were the first to exploit their inventions commercially on a large scale. By 1904, over 50 systems had been patented (Cusack, 1987).

One of the most successful—and relevant for our story—was François Hennebique's system, which was initially patented in France in 1892. The system used plain round bars with fish-tailed ends and stirrups of flat strips to support monolithic concrete structures and reinforced slabs for flooring. It was one of the simpler of the systems then being patented, but it was also one of the most successful commercially. Numerous historians marvel at Hennebique's entrepreneurial spirit and his transformation of his small company into a multinational empire devoted to the construction of reinforced concrete buildings. As Cusack recounts,

> between 1892 and 1897 … (Hennebique's) commercial organisation for reinforced concrete expanded from one technical office, two engineers/draughtsmen (and no licensed contractors yet) to 17 offices, employing 56 engineers and draughtsmen, with 55 licensed contractors. By 1909, there were 62 offices, located in Europe (43), the USA (12), Asia (4) and Africa (3) and Hennebique's system was by far the most popular reinforced concrete method. (Cusack, 1987, p. 63)

In an early version of design-and-build, architects and contractors wanting to work with Hennebique's technology purchased both the design and the services of specialists responsible for overseeing onsite construction. At the heart of the system was a novel organizational innovation, namely the *bureau d'étude* or research office (Simonnet, 2001). Each of Hennebique's offices had its own office. Their role was to produce designs and oversee technical expertise. These offices also conducted extensive material testing. In 1898, Hennebique launched *Le Béton Armé* ('armed concrete' or reinforced concrete) a journal specifically devoted to his method in which he diffused knowledge of reinforced concrete in general and his system in particular. The journal both advertised the system and published practical rules and guidelines. In the following years, similar journals were launched by competitor firms in other countries, helping to advertise and diffuse knowledge of the new material.

Hennebique, however, did not rely on formal knowledge or channels of transmission. Instead, his empire rested on personal contacts and training (Cusack, 1987; Delhumeau, 2001). Those firms wishing to acquire a Hennebique licence often sent their engineers and contractors to Paris for special training courses. This practice reflected Hennebique's greater reliance on experience than science. Every Hennebique building was closely monitored, with continual onsite testing of materials and near standardized practices. In many cases, French workers and engineers were brought over to construct the projects. The result was a high quality of building, despite the relative lack of formal theorizing.

One effect of this new commercial system was a change in the social relations between internal stakeholders. The specialist firm research offices and journal mediated the relation between the firm and the architect, displacing traditional relationships and distributions of authority. A second effect was the insertion of Hennebique inspectors on site and an associated restriction in the knowledge base and autonomy of construction workers (Simonnet, 2001).

While Hennebique and his firms did not engage in extensive scientific research, his enterprise contributed to a growing scientific culture around reinforced concrete in the last decade of the century. In 1903 the first professional association for reinforced concrete contractors was formed in France, the Chambre Syndicale des Constructuers en Ciment Armé. From 1892 to 1900 an official French commission studied the methods of calculation and construction practices in use (Hamilton, 1956). Firms and patent holders, such as Hennebique, fought hard to influence the content of the report (Simonnet, 2001).

In terms of socio-technical network analysis, the above account situates the early commercialization of reinforced concrete in a network of near monopolistic firms with experience-based technical knowledge, supported by a system of patents and licences, on which architects and contractors depended. It also documents the co-production of commercial buildings and abstract theoretical knowledge by engineers in firm research offices, in collaboration with independent scientists. The strength of this network depended, in part, on the protection which licences afforded, the lack of specialized knowledge outside firms and the absence of formal education, teaching manuals and official codes of practice and regulations. After 1900, their influence lessened somewhat on the Continent as technical colleges in France, Switzerland, Germany and Scandinavia introduced courses in the use of the material and government codes of practice supported a more open market.

The arrival of the latecomers: the commercialization of reinforced concrete in the UK and US

As the following discussion indicates, all of these elements were present in the British and American cases, albeit in different configurations, with different consequences. The next two sections consider the subsequent uptake of reinforced concrete in Britain and the US after 1900. The discussion is organized around the question of how to explain the relative delay in British engagement with reinforced concrete compared to the extremely rapid uptake in the US.

British reluctance (to adopt reinforced concrete)

The literature on the construction industry in general and reinforced concrete in particular is full of observations concerning the delay in British uptake of the new material. In 1948, Prof. Marion Bowley wrote a book on reinforced concrete in which she asked: 'why what has come to be a standard method of building was so slow in taking root in this country?' (1960, p. 12) and in 1956, Prof. A.L.L. Baker wrote: 'To-day, Great Britain is probably the last country in the world to embed large quantities of structural steel in concrete cladding for the support of tall buildings' (1956, p. 182). For scholars not immersed in this story, the observation may seem strange. Most construction scholars can cite examples of the early use of the material which they've either seen or read about. This seeming contradiction can be explained, first by the small number of reinforced concrete structures, relative to developments elsewhere in Western Europe and the US and secondly, by the identity of those building the British buildings.

Until World War II, steel, rather than reinforced concrete, remained the new structural material of preference. From the late 19th century onwards reinforced concrete was increasingly used in the UK for pavements, floors, roofs and even beams, but not for framed construction (Cusack, 1987; Brown, 2001). More importantly, almost all of the use of reinforced concrete in the first decade of the century was by foreign firms with British licences and patents.

The largest player was Hennebique. The first Hennebique building was a provender mill in Swansea, which was built in 1897 and supervised by L.G. Mouchel, Hennebique's agent in the UK. Calculations and designs were produced in Nantes and sent over, as were some workers (Newby, 2001). Within a few years, Mouchel's firm dominated the market. By 1911 there were 1073 reinforced concrete works in Britain using the Hennebique system (including full-framed buildings, reservoirs, bridges and other structures); this represented approximately 70% of all reinforced concrete structures (Cusack, 1987). As on the Continent, Mouchel actively protected his monopoly. Employees were required to sign agreements that they would not work for other specialist firms for five years after leaving the company and Mouchel actively pursued companies in the courts which used the Hennebique system (Cusack, 1987). Starting in 1909, Mouchel launched his own English language journal, *Ferro-Concrete*, devoted to transmitting knowledge of the material and promoting the Hennebique system.

The first serious challenge to the Hennebique system monopoly came, not from competitors—although they did begin to enter the market after 1904[1]—but from British professional institutions. A survey of the transactions of the Royal Institute of British Architects dates architectural interest in the material as far back as the 1860s (Hurst, 2001). In the 1860s and 1870s professional opinion was divided and the Institute did not sanction use of the material. Both the interest and ambivalence can be ascribed to the direct threat which the licensing system posed to the monopoly of architects over design and construction.

Between roughly 1904 and World War I RIBA, together with other professional organizations, campaigned to break the links supporting specialist firms' monopoly over the use of the material (Cusack, 1986). The attempt involved the publication of an independent journal, the creation of a separate institute, the compilation and publication of brochures and textbooks on the theory of the material and its use and the formulation of professional guidelines. Whereas on the Continent, these activities were promoted by industrialists and more specifically by specialist firms, in Britain they were developed to counter the influence of such firms.

Key developments in the campaign to wrest control from the specialist firms include (1) the publication in 1904 of the first manual in English by Charles F. Marsh, entitled *Reinforced Concrete*; (2) the formation of a Reinforced Concrete committee by RIBA to develop guidelines for the use of the material; (3) the establishment of a new independent journal, *Concrete and Constructional Engineering*, in 1909 to disseminate independent information on individual buildings and practices; and (4) the creation of the Concrete Institute in 1908 for architects, engineers and contractors (Hamilton, 1956; Cusack, 1986).

The RIBA committee was composed of members from the District Surveyors' Association, the Institute of Builders, the Incorporated Association of Municipal and County Engineers, the War Office, the Admiralty and three individual members, including Charles F. Marsh, Professor W.C. Unwin and Colonel F. Winn. The Institute for Civil Engineering was invited to join in the effort, but refused. The result was a committee of eminent architects and officials, with little to no practical knowledge of reinforced concrete or experience of working with the material. Nor did the committee consult with specialist designers, at least not officially. Assessments at the time deemed the report to be both insufficient and difficult for architects (Cusack, 1986). The RIBA committee's recommendations provided the basis for London County Council's 1909 regulations (LCC General Powers Act) which were to dominate the use of reinforced concrete until their revision in 1933 (Hamilton, 1956).

Following World War I, designs that complied with these standards were generally approved and any builder could be engaged to work to those plans. Thus, while specialist firms with licensed systems continued to work in Britain they lost their monopoly and the standard of building fell considerably (Hamilton, 1956). The result was a loss of confidence in the viability of the material and the oft observed delay in the uptake of the material. Winch goes so far as to hold professional institutions responsible for a 20-year delay in the British shift from load bearing masonry to structural framing (Winch, 2007).

In 1920 the government created the Building Research Station (BRS) to develop materials science, including the study of reinforced concrete. The BRS' work both contributed to scientific developments and provided the basis for later revisions to the regulations. But, in contrast to the situation on the Continent (and, as indicated below, in the US), its activities remained relatively isolated from the daily activities of either professional societies or construction firms. Moreover, the BRS was established well after official regulations had been instituted, thus limiting its influence over them.

In sum, whereas on the Continent, reinforced concrete developed in a network which integrated and linked the interests, activities and understandings of commercial specialist firms, scientific experts and government officials around a body of shared knowledge and associated codes of practice, in the UK, these groups worked in their own circles and while they influenced one another, the links were punctuated and tenuous.

American embrace (of reinforced concrete)

The American case stands in sharp contrast to the British one. A key difference lies in the articulation of scientific developments, legal developments and onsite practices. Two factors would seem to have been crucial in accounting for this difference. The first involves the type of patents and licences issued in the US and the second concerns the system of higher education and the relation between American universities and industry. A third factor concerns the 'fit' between the practices that developed around the American use of reinforced concrete and a more general movement to standardized, scientific management and the deskilling of construction workers (Slaton, 2001).

In the late 1890s a number of Continental firms set up shop in the US, competing with comparable American companies. Whereas in the UK, patents and licences were granted for entire systems, in the US, the focus was on individual products, with architects and contractors free to mix and match techniques and materials. Some builders went so far as to advertise themselves as independent, presenting this as a positive selling point (Slaton, 2001). The result was a much larger, much more open market with numerous manufacturing firms actively engaged in promoting the use of their materials as widely as possible.

The central role of university-based professors and university-trained engineers in the commercialization and uptake of reinforced concrete is specific to the United States. In the background lies the public service character of American universities. This can be traced back to the creation of land-grant colleges in the 1860s. These were state funded institutions with an explicit remit to serve agriculture (and the economy more generally). Their practical, social orientation was shared by private institutions. A second, related, feature of American higher education was the very active involvement of industrialists in funding and curriculum development. In the foreground stands the emergence of materials science as a university-based subject and its introduction into the basic curriculum for engineers.

The relation between professors of materials science and the reinforced concrete industry developed on a number of levels. First, industry actively funded the buildings and laboratories needed to introduce these new subjects into universities. In exchange, university labs offered their services testing materials for individual projects. In this way, the work which the Building Research Station did in the UK, Americans conducted in land-grant colleges and universities on a much greater scale and with a commercial dimension absent in the UK. By 1927, 30 states had land-grant universities with some type of engineering experiment station in operation or under development. While the largest construction firms had their own in-house testing facilities, smaller and medium sized firms relied on university labs (Slaton, 2001).

Secondly, universities developed new courses designed to train engineers in materials testing and quality control. Teaching staff used curriculum development to produce new techniques and protocols for materials testing, including testing kits to be used on site. Students spent their summers in internships on construction sites and found jobs after graduation on those same sites. According to Slaton (2001), their presence marked a transformation in the organization of work. Traditional craftsmen were replaced by unskilled workers on the one hand and university-trained engineers on the other hand. The first worked mixing, pouring and transporting concrete, while the latter supervised the material (not the workers). Like the *prescripteurs* from the Continental *bureau d'études*, university-trained engineers served as brokers for the specialized knowledge deemed essential to the construction of reinforced concrete buildings. In practice, they worked as guarantors of quality control, testing hundreds, if not thousands of samples in temporary laboratories set up on site as work progressed.

A third type of relation involved the active participation of university professors in the development and standardization of abstract knowledge about concrete and its translation into standards and regulations. Whereas in the UK this activity was initially concentrated in the hands of architects, in the US it was led by industry and university-based engineers. Two organizations spearheaded by development of standards: the American Society of Civil Engineers (1852) and the American Society for Testing Materials (1898). In 1898 the ASCE created a committee to address the problem of regularizing cement tests. The committee found a diversity of different tests and produced a set of guidelines on how to administer tests. Their recommendations provided the basis for the ASTM's 1904 recommendations on cement use. Within a few years they had been adopted by most leading construction firms as part of 'best practice' and incorporated into most textbooks. In 1909 they were codified. For Slaton, the striking feature of this story is the way in which these recommendations combined standardized tests, which could be administered by anyone and the exercise of discretion, which only trained experts could be trusted to possess (Slaton, 2001), thus securing the presence of university-trained engineers on site.

According to Slaton and in the language of SCOT, the story of reinforced concrete in the US between 1900 and 1930 is a story of the way in which materials scientists successfully stabilized reinforced concrete and inserted the technology and associated practices (including quality testing) into the construction industry, thus creating a professional niche for themselves and their students as technical experts. While the techniques and form of material concrete were roughly similar across Europe and the US, the exact specifications, ways of working, types of buildings, legal framework and social division of labour supporting them differed considerably. And these differences can be attributed to differences in the identity of relevant actors involved in the elaboration of standards and in the commercialization of the material and in the relations between them.

In sum, the relevant artefact (for any study of materials in use) is not reinforced concrete *per se*, but concrete in association with published standards and specifications, management practices and a particular social division of labour between experts, architects, contractors, manufacturers and site workers. The uptake of the material varied with the distribution of expertise on site and in the coordination between internal stakeholders and the differential involvement of experts in the design of standards and quality control.

Case 2: Using and translating technological artefacts: BSLink in four organizations

Our second example explores the contribution of socio-technical network analysis to the study of IT. The research presented in this section explores the implementation of a piece of building services 3D design software called BSLink in four different organizations. The empirical research adopted an approach which 'follows' the artefact (Latour, 1996) from the developer's offices into the user organizations and investigates the networks and practices that were elaborated around its use. The research paid particular attention to the goals of each organization, the problems that BSLink was being asked to address and the changes to existing practices and professional jurisdictions which this introduced. As the discussion that follows indicates, one of the contributions of this approach lies in its ability to underline the type of accommodations—in everyday practices, in professional identities and in the role of different stakeholders—which the diffusion of a new technology and associated elaboration of a new socio-technical network demands. For the purposes of the paper, the aims and activities of each organization have been presented as more homogeneous than they actually were.

The technology

BSLink is a building services systems package (pipe and duct work, electrical systems and so on) which produces 3D models. The complexities of designing building services makes 3D models attractive by allowing for more detailed coordination than traditional 2D design. The artefact itself is an add-on CAD (computer aided drafting/design) package for the industry standard AutoCAD software. As such, it is intended to be used by existing AutoCAD users (see Senker and Simmons, 1991 for a discussion on the division of labour between drafting and design work), and utilizes those users' familiarity with the AutoCAD interface. It uses 'intelligent objects' to store information on component parts. This includes spatial information and less usually available data on other attributes such as how the component connects to other components, part numbers or costs. Systems are modelled either by converting drawn lines into 3D objects or by selecting existing components from a user-editable library of objects (valves, pipe-work, ducts, etc.) that comes with the software. By dragging objects from the library to the model, complex systems can be quickly produced, which retain the attribute information. As well as allowing spatial coordination with other design elements, the models can be used to automate the production of bills of quantities and cost information or to provide facility managers with a virtual model that includes part numbers and servicing schedules.

From this description, BSLink might be seen as stable artefact; it calls upon CAD drafters to incorporate a large amount of component attribute information into their 3D models and to deploy this single information rich model across the supply chain, from design through construction to operation and maintenance. However, a review of the goals and uses which different users have for the tool belies this image and attests to the interpretive flexibility of the tool.

What the developers wanted

The developers of BSLink were driven by two distinct objectives. First, they were keen to try and establish BSLink as the main product for 3D services design as this was seen as a new market for them with much potential. Secondly they wanted to position BSLink as part of a system for the automation of procurement functions, which placed the developer at the centre of exchanges between contractors and suppliers. In order to realize this vision, a number of practices would have to be transformed. BSLink users would have to model building services systems in 3D using objects from a library containing supplier-specific components. The model would then be used to automate the production of bills of quantities (BoQs), which would be distributed to the relevant suppliers. Suppliers would then prepare the order and electronically invoice the organization.

This sounds simple enough, but such a network of automated procurement presumed the alignment of a host of entities. First it assumed that suppliers would provide cost and component information and that someone would enter the data as objects in the library. Secondly, it assumed that users of BSLink would develop their designs around pre-specified suppliers' objects rather than generic ones. This shifted the choice of components from the engineer to the CAD users and from the point of actual purchase and installation to the initial design stage. Thirdly, the developers' vision depended on the introduction of a range of other artefacts which would be used to automate both the transfer of BoQs from BSLink to suppliers and invoicing. Finally, their vision presumed a radical reorganization of the supply chain, since the organization doing the CAD design is not always the one purchasing and installing the components on site.

At the point at which the research was conducted, BSLink had been adopted by each of the four organizations examined, but the network supporting its use in each case had yet to be stabilized. The developer was negotiating with a number of suppliers and working on a hub-based IT system which would incorporate BSLink and perform the transfer of BoQs and invoices. But when BSLink was followed into user organizations, different sets of interests, problems and uses were found to be at play.

What the users wanted

One of the most striking aspects of the four different organizations studied was their heterogeneity with respect to why BSLink had been selected. Each of them worked with a different set of goals and privileged different aspects of BSLink. Interpretations and uses varied with the type of firm, its relation to clients and the particular distributions of authority over the design process.

Each of the organizations (or rather each of the representatives consulted) identified a distinct set of problems that BSLink had been adopted to address and expectations of what it would do. The discussion that follows outlines the different types of firms included in the study and their vision for BSLink. It then moves on to examine the socio-technical networks in which this artefact was inserted, the type of accommodations which it required and the relative strength of different links in the socio-technical network supporting its use.

OrgA is a large, international architecture and engineering design consultancy. As such, it is generally positioned between the client and the contracting organizations. There was a particular interest in maintaining control over design information as it flowed to contractors. It viewed BSLink as a solution to the complexity of building services design. The tool promised to provide 'better and more complete information' downstream to contractors; it also offered the possibility of producing a fully specified as-built model with reduced opportunities for design changes further along the process. However, to realize this aim, OrgA needed to incorporate specific supplier components into the models, rather than generic objects.

OrgB is a specialist M&E (mechanical and electrical) designer and contractor. Like OrgA, OrgB saw BSLink as offering a solution to the complexities of building services. But in contrast to OrgA, OrgB also presented BSLink as part of a strategy to coordinate more effectively with other organizations involved in the design process—notably architecture and structural design firms. Prior to the introduction of BSLink, designs had been provided by these organizations for OrgB to coordinate their services. These were generally 2D plans, rather than fully spatially coordinated models with the coordination of design information largely occurring on site. This could result in discrepancies between the design and what had actually been built. Hence services often needed to be altered and reworked on site—an inefficient and expensive process. One of OrgB's aims in adopting BSLink was to use 3D to more effectively coordinate building services design with the rest of the building, and thereby remove those onsite discrepancies. Thus, whereas OrgA was committed to including supplier-specific components in its 3D modelling, OrgB did not need this information to meet its goals for the tool. Instead OrgB used generic objects of the correct dimensions for coordination. What was key for OrgB was the development of a set of standards for generating 3D models across the whole of the design process.

OrgC is a specialist design, construction and facilities management organization, working solely in the pharmaceutical sector. As in the above-mentioned organizations, BSLink was used to deal with the complexity of building services designs. But, in contrast to OrgA and OrgB, OrgC was much more client oriented. 3D models of facilities were produced to show clients what buildings would look like and as training material for eventual factory-floor workers. These 3D visualizations were felt to be highly influential in winning contracts from clients and in informing them throughout the design and construction process.

Finally, OrgD is a large contractor which does not do any actual design work. Its interests are fundamentally in increasing its profit margins on projects. As OrgD is a main contractor, the impact of rework and spatial inconsistencies that are not discovered until on site seriously affects its profits. BSLink was used alongside other 3D software to take the information supplied by designers and build a virtual coordinated model before onsite work began. Any spatial coordination issues were referred back to the originating designers to rectify. This activity was not within the contractual remit of the organization, but was seen to reduce onsite problems and therefore costs.

The range of uses and goals for BSLink across these organizations demonstrates both the diversity of problems BSLink was being drawn on to address and the extensive interpretive flexibility of the artefact. It was enrolled as a tool for maintaining the integrity of design information further down the supply chain (OrgA), as a way to integrate and coordinate building services information with other design information (OrgB), as a visualization tool to demonstrate designs to clients (OrgC), and as part of a method of checking design information to reduce the inconsistencies. It was the ability for BSLink to sustain these diverse interpretations and interests that enabled its alignment within these different socio-technical networks.

User networks and emerging practices

These differences in problem specification and envisioned uses called for and supported different socio-technical networks. In all four cases, the reliance of BSLink on the same parent AutoCAD software and involvement of observing drafters in the initial implementation meant that certain components were shared. Each of the four socio-technical networks elaborated around BSLink included CAD drafters, BSLink itself, other IT hardware and software and design artefacts such as 2D schematics. However, a closer examination of these networks beyond immediate use and of each organization's efforts to align these networks with individual firms' interests revealed substantial differences in the actors and objects engaged in the network. These shaped both BSLink and the practices performed across (and beyond) the four organizations.

At OrgA there was extensive interaction between two *relevant social groups*, namely the CAD drafters and in-house engineers and designers. This always took place around particular artefacts—either the model on the computer screen or a large-form printout of it. As this suggests, non-IT artefacts remained central to the activities of designing and drafting (Harty, 2008). At the same time, drafting practices were transformed in the transition from 2D to 3D (something that took some 'getting your head round'). New practices can be seen in the increased interaction between designers and drafters and in the generation of objects for the library. Producing objects for the component library was a resource-intensive task; about a third of the time spent on BSLink was devoted to building objects based on suppliers' paper catalogues.

Overall, the network supported the practices of producing 3D models of services effectively within the organization. It was in extending the network beyond these reasonably stable relations between core actors that OrgA met with opposition. BSLink was positioned as a way to maintain the integrity of the design down the supply chain, but to do this the network required expansion outside the organization and the alignment of other actors and artefacts. Contractors would have to take the model and faultlessly reproduce it on site. This posed both jurisdictional problems of contractor authority and practical problems of how to import 3D images on to the physical site.

From the perspective of contractors, the use of BSLink marked a radical break with usual onsite practice which traditionally involved extensive interpretation of 2D schematics and problem solving. BSLink represented a serious restriction of the scope of contractors' and subcontractors' decision making. Just as crucial was the problem of how to introduce 3D virtual models on to the building site. Artefacts such as mobile PCs and viewing terminals were less than satisfactory given the challenges of the onsite environment and BSLink was not capable of producing accurate paper-based sections of the 3D models. Links between BSLink, contractors and workers were thus weak. Negotiations were also ongoing with another group—the component suppliers who had little interest in producing and supplying updated catalogues after their products had already been bought and were being used. Providing object libraries held no extra benefit for them.

In contrast to Org A, Org B successfully created strong links between BSLink, designers, drafters and workers. Their success can be attributed to the integration of traditional and new practices and additional artefacts which supported the envisioned use of BSLink. OrgB made a major effort to persuade contractors and workers that it was in their interests to adopt this new tool. In addition to BSLink and other CAD artefacts, viewing software and site-office based terminals were introduced to show where and how services were going to be installed and to mark up onsite work. Paper was used alongside BSLink, both in designing and drafting and in the form of printouts used to supplement 3D viewing, especially on site. This was an extension to usual design and drafting practice, with drafters regularly attending briefings on site to assist site managers in using the model and artefacts. It was also an extension of the socio-technical network around BSLink out of the CAD office and on to the building site. For the onsite groups, the combination of traditional methods of marking up work with the digital 3D models and drafter support persuaded them to work with the new technologies.

However, extending the network beyond this proved more challenging. OrgB wanted the other design disciplines to produce 3D models, so that the building services could be accurately coordinated with them. Towards the end of the case study, it had produced and was beginning to circulate a set of standards and an accompanying document outlining conventions for producing 3D models, not just for building services using BSLink, but for all of the design disciplines, including architects and structural engineers. This was a clear attempt to translate the interests of the other designers to connect with its own by providing a tested and coherent set of work protocols that would be more effective than existing methods and which only required the other disciplines to follow them.

For OrgC the network supporting BSLink was again shaped rather differently in terms of both actors and artefacts. As indicated above, OrgC was using BSLink primarily as a marketing and communication tool for clients and end-users and so BSLink was being combined with a range of digital visualization tools, many of which were not construction specific. This had the effect of reshaping the role and expertise of the drafters themselves. Rather than being positioned as drafters with a working knowledge of building services, they were moving towards being specialist IT users, whose skills were located in the numerous non-construction-specific visualization packages they used. This shift was seen not just in the recruiting of new staff, but also in the reconfiguration of the skill sets of existing drafters.

OrgD was assembling a new network of drafters with the specific purpose of checking and coordinating the information it received from external designers and developing a new set of practices to act as a buffer between external design and onsite work. This involved taking all of the design information supplied for a particular project, and using it to produce a complete 3D model of the building. But unlike OrgA, the drafters at OrgD did not interact directly with designers. Instead, communication with designers occurred through the production of RFIs (requests for information). These effectively flagged up any instances where design information was incomplete, or where there were inconsistencies between different design elements. The RFIs were paper based, and were generally faxed to the designers in question, who would then address the problem. Although this could result in delays, it did allow for many design issues to be resolved that would normally only be discovered on site. These practices were highly unusual for a contractor to perform, but OrgD's interests lay in exposing the extent of the problem with the aim of the design organizations taking on the practices of checking and coordination themselves. Using the number of RFIs (which could run into the hundreds for a project) as leverage, OrgD was trying to translate the interests of these organizations to producing more coordinated information.

As these brief vignettes suggest, the implementation of BSLink, and one could suggest any new technology, involved a transformation of daily practices in ways that engaged new actors and entities, heightened the influence or importance of some and diminished that of others. At times, relevant social actors were translated and enrolled into new formations—persuaded to refashion their daily activities, identities and interests in alignment with the promoting organizations' vision for the new tool. At other times they objected and resisted incorporation into these transformed networks. In all cases, the *interpretive flexibility* of the tool (both within a particular setting and across settings) meant that such diverse uses and, perhaps more importantly, different socio-technical networks were possible.

In each case the elaboration of socio-technical networks developed within (different) limits, and each organization came up against a range of difficulties and resistances when attempting to expand the network and align others within its own expectations and interests. In most cases, the difficulties were not technical (although the problems of IT on building sites is one exception) but rather social. They involved the extent to which everyday practices, roles and identities could be reshaped to support the new tool and its envisioned use. The interpretive flexibility of BSLink allowed much opportunity for shaping, but only within these limits.

Analysing the development of socio-technical networks and interrogating their limits can help to explain how and why a particular artefact is or is not adopted by a particular organization in the service of a particular set of goals. It also sheds light on the ongoing development of the tool itself and on the social effect of technological innovation on the distribution and valorization of competencies in different networks. Viewed from this perspective, technological innovation is always (also) a bid to (re)define the work process, while the negotiations surrounding the uptake and use of new objects are inevitably also struggles for the definition and control of a new work jurisdiction (Abbott, 1988).

Case 3: Social technologies: environmental assessment tools

The final case in our brief *survol* of different types of construction artefacts and the light which socio-technical network analysis might shed on them involves the introduction and proliferation of environmental assessment tools in the construction industry since 1990. More specifically, it focuses on the development and diffusion of BREEAM, the BRE Environmental Assessment Method.

The interest of assessment tools in general and BREEAM in particular for our discussion is threefold. First, it provides an example of a specifically social or political technology, designed to manage and alter behaviour. Secondly, it provides another illustration of *interpretive flexibility*. As in the case of 3D-CAD technologies, it shows how different interpretations of the same formal artefact are tied up with different uses and supported by different socio-technical networks. Finally, like the cases of reinforced concrete and BSLink it draws attention to the *social embeddedness* of technologies and to the contribution which an analysis of the relative strengths and weaknesses of links might make to an understanding of *stabilization* and uptake.

In contrast to the discussions of 3D-CAD technologies and reinforced concrete, our treatment of BREEAM is largely speculative. While there is a growing literature on the technical development of assessment tools and their contribution to environmental and sustainability agendas, little empirical work has been done on the social forces shaping their development or on their integration into work-site practices. The discussion which follows draws on a number of sources, including the small but growing academic literature, trade journals such as *Building Magazine* and *Construction News*, personal blogs and anecdotal evidence garnered in informal discussions. Our aim is to outline the types of questions and insights which a more systematic socio-technical network analysis of BREEAM might entail.

The success of BREEAM can be measured by its ability to monopolize the definition of what counts as a green building, by its effect on building practices and by its environmental impact. Most scholars focus on the latter. Our focus on BREEAM as a social technology draws attention to the first two. Stated differently, a socio-technical networks approach provides a basis to explore the establishment of BREEAM as a *necessary point of passage* in the evaluation of environmental performance, with the attendant transformation of interests and practices and emerging consensus over interpretation which *closure* entails. Whereas most of the tools studied by STS scholars have achieved a certain degree of closure, BREEAM (like BSLink) remains relatively open.

The application of socio-technical network analysis to BREEAM suggests two distinct types of study. The first is a historical study of the development of the tool, documenting the shifting networks of actors, objects and understandings supporting the ongoing transformation of BREEAM as an object. The second type of study involves a study of BREEAM as a social technology, designed to transform buildings and building practice.

As the reader will appreciate, in the first case, BREEAM is analysed as a physical artefact (product) supported by a network of actors and understandings which shape its ongoing development. The problem is one of innovation and product development. In the second case, BREEAM is conceptualized as a social technology, designed to influence behaviour. The focus is on BREEAM as a process and the research calls for in-depth case studies of specific assessments. The contribution of socio-technical network analysis in this instance lies in the study of environmental assessment as a process which takes place in the context of a broader process, namely that of design and construction. A central contribution of this type of analysis lies in the insights it provides into the effect of new demands on the industry on existing procedures.

For a socio-technical history of BREEAM

BREEAM was the first environmental assessment tool of its kind to be created. It was introduced by the BRE in 1990 and since then it has experienced a number of reincarnations. Over the course of the past 19 years, the BRE has produced many different versions of BREEAM for different types of buildings, ranging from homes and offices to schools, prisons and hospitals. It has expanded to include a bespoke version, different country versions and most recently, a post-occupancy version and BREEAM for Communities. Whereas the original BREEAM tool consisted of a 19-page report with 27 credits, the current Office version involves a 350-page report with 105 credits.

As an environmental assessment tool, BREEAM has had considerable success. It is currently touted as one of the governments 'mandated mechanisms' for sustainable procurement (e.g. DEFRA, 2007; OGC, 2008). Local authorities often require BREEAM assessments as do organizations such as English Heritage. The UK Green Building Council (UKGBC) recently overcame its reluctance and singled BREEAM out as an essential tool for green construction (Kennet, 2008). At the same time, BREEAM's place in the market of assessment tools is far from secure. Whereas BREEAM began as the only tool of its kind, it currently exists in a market of assessment tools (Cole, 2006), with a number of equally successful competitors, including the US-based LEED and the Australian Green Star. In addition numerous construction and consultancy firms are currently developing their own in-house tools, many of which overlap with BREEAM's jurisdiction.

The market for assessment tools is thus a major driver in the ongoing development of the tool. But this claim obscures as much as it reveals, for it leaves open the question of who and what constitutes that market (given that it's not a neo-classical market of individuals whose activities are coordinated through a simple price mechanism). What the different actors involved want, how those demands are exercised and how and why the BRE has responded one way rather than another all remain to be specified. It is here that socio-technical network analysis can be helpful. The discussion that follows identifies some of the relevant actors, possible interpretations and types of closure processes which might account for the relative success of BREEAM in the market of tools.

Who has an interest in BREEAM (relevant actors)?

A number of different actors (or in this case, organizations) support the use of BREEAM and shape its ongoing development. The first is, of course, the BRE, itself. To secure BREEAM, the BRE has inserted it in a network of actors and artefacts, all of which depend on the BRE for their authority. Like reinforced concrete at the beginning of the 20th century, BREEAM was designed to combine technical, standardized knowledge and expert judgement. BREEAM assessments are generally carried out by licensed assessors and ratings are verified by the BRE which certifies building performance. The BRE runs regular training courses and seminars for users. While the BRE recently decided to make the BREEAM manuals public, its website warns that they have been designed for use by BRE trained and licensed assessors and 'should be used by non assessors for reference only (in accordance with the Terms and Conditions of use)' (BRE Global Ltd., 2009a). In this way, the BRE has both produced and linked itself to the social authority of a new type of professional.

A second type of actor is the government. The British Government plays a variety of different roles in relation to BREEAM, including legislator, client and policymaker. Relevant government actors thus include legislators who vote on regulations which then influence the categories and criteria in BREEAM, government officials in charge of procurement and policymakers who mandate the use of BREEAM in their projects. Finally, a number of recent funding schemes to support environmental improvements link finance to BREEAM assessment levels (Burrows, 2009).

Proponents of BREEAM present the fit between BREEAM and the UK institutional context as an important market advantage. As James Parker of the Building Services and Research and Information Association (BSRIA) notes: 'BREEAM will probably always come out on top in the UK, simply because it is imbedded [*sic*] in the system' (2009). But this comment raises the question of what is the relevant system. The link between BREEAM and UK legislation is only as strong as the national market. To the extent that firms and clients seek recognition outside the UK, other assessment methods may also appear attractive. This may be one reason why BREEAM has recently signed an agreement with LEED and Green Star to coordinate their system of energy measurements (Kennet, 2009).

A third set of actors is comprised of industry representatives. Their influence is exerted in two ways, first as clients who employ BREEAM assessors and secondly as policymakers who exert their influence through joint industry/government advisory bodies, as members of the BREEAM board or as advisors and consultants to the BRE on the ongoing development of BREEAM. Key organizations include the UKGBC and the Business Council for Sustainable Development whose judgements on BREEAM directly affect its reputation and uptake and who weigh in on the ongoing development of the tool. While many of these people use BREEAM, most also recognize its limitations and many are involved in the development of complementary and alternative assessment methods.

How they think about BREEAM (interpretive flexibility)

The identification of relevant actors and artefacts serves to map out the network of relevant players. A second step in a socio-technical network analysis involves the study of meanings. Research in this stage focuses on the interpretations which different actors have of BREEAM. The focus is on how these shape the design of the tools itself as well as its uptake and use. While this type of analysis is beyond the scope of this paper, a study by Dammann and Elle (2006) on the meanings and expectations of environmental assessment methods in Denmark sheds some light on the types of variations one might expect to find in the UK.

A basic premise of their study is that different users mean different things when they talk about 'green buildings' and that these differences shape their understanding of and criteria for assessment methods. Stated differently, assessment methods, like other technologies, display *interpretive flexibility*. For example, the same life cycle assessment (LCA) technique may be seen by one set of users to be functioning well and by others as non-functional depending on their interpretations.

In their study, the authors identify four distinct *technological frames*, held by different relevant actors and supporting different types of tools. These include: (1) *a public relations frame*, associated with professional clients, administrators of buildings and politicians in local authorities; (2) *a scientific frame*, expressed by researchers and consultants with an engineering background; (3) *an aesthetic-holistic frame*, largely associated with architects; and (4) *a layperson-sensualist frame*, expressed by non-professional private clients, residents and other users of buildings.

While we do not have the space to enter into the content of each interpretation, we can illustrate the differences by contrasting the contents of the public relations and scientific frame. Whereas the first viewed assessment tools primarily as

> a means to document their environmental commitment to their respective target groups (employees, residents, citizens/the constituency) in order to obtain a favourable public image and as a means to manage the costs for the building's operation … [the latter treated them as] a vehicle to sell natural-scientific and technical expertise and to evaluate buildings scientifically and precisely to ensure that the efforts made actually lead to environmental improvements. (Dammann and Elle, 2006, p. 394)

In terms of the tools themselves, proponents of the professional frame called for simple, operational and convincing indicators that avoided conflictual issues such as life style changes, but covered indoor climate. Adherents to the scientific frame, in contrast, favoured more complex LCA-based indicators which focused on regional and global environmental issues such as climate change, ozone depletion and consumption of scarce resources. In contrast to the public relations view, proponents of the scientific frame were singularly unconcerned with issues of indoor climate (2006, p. 394).

Strong vs weak ties

In reflecting on the effect of socio-technical networks on the ongoing development of open artefacts such as BREEAM, it's important to consider two additional issues. The first concerns the relative strengths of different ties, thereby indicating the stability of the artefact and opportunities for change. The second concerns the actors and considerations that are excluded from the network, and thus rendered voiceless or ignored. The strength of ties embedding BREEAM in a network composed of the BRE, licensed assessors, UK building regulations, government policies on sustainable procurement and local authority requirements for BREEAM assessments all help to explain how BREEAM has come to be the most widely recognized environmental assessment tool around. At the same time, not all of these links are equally strong. While the UKGBC recently endorsed BREEAM, it also produced a report on the proposed Code for Sustainable Buildings which supported a variety of different rating methods (Willoughby, 2009). Similarly, while the actors in this network are beholden to BREEAM, the links that bind them are relatively weak. Most assessors also do other things, just as most environmental consultancies also offer other services. In this sense, the links between them depend on ongoing client demand and on government support for environmental assessment in general and BREEAM in particular.

Assessment as a process

While BREEAM began as an assessment tool, its proponents envision a wide range of uses and effects. These include the involvement of BREEAM in the design process, in the assessment of environmental performance, in the setting of standards for best practice, in the education of stakeholders and in the marketing of green buildings (Crawley and Aho, 1999; Cole, 2005). While much is known about the promise of BREEAM, far less is known about its actual uses or about the conditions shaping different uses.

The relevant actors in a BREEAM assessment include the licensed BREEAM assessor, who may or may not be in-house, and those people on the design and project teams who are involved in the assessment. Who they are, whether they include the client, the architect, contractors, persons responsible for procurement, specialist engineers or other consultants in the assessment process is an empirical question. These individuals, along with the measurement devices and paper trails generated by the assessment itself, constitute the socio-technical network associated with that particular enactment of BREEAM.

In terms of the meaning of the assessment method, the BRE website lays out the interpretation which it hopes users will internalize.

A BREEAM assessed development can mean:

- Functionality, flexibility, maintainability and durability
- Lower embodied and operational environmental impacts
- High user satisfaction, quality and control. (BREEAM, 2009b)

While no systematic research has been done on the topic, initial impressions suggest that this is not the only set of associations which stakeholders have when BREEAM is evoked in conversation.

Environmentalists often see a tool which short-changes them and the public when it comes to sustainability by focusing on narrowly defined design features of the building and ignoring the impact of actual performance and broader environmental and social effects. Designers and contractors often see it as a tick-box exercise with little relevance to procurement processes. Marketing divisions see it as a way of publicizing corporate social responsibility. Finally, trained assessors presumably see an important arena of expertise over which they hope to establish a monopoly. Few people that we spoke to identified it as a tool to enhance functionality or flexibility. How and why these differences matter and what demands they lead stakeholders to place on the ongoing development of the tool are central research questions which socio-technical network analysis promises to answer and which would help to account for the ongoing development and uptake of the tool.

While relatively little research has been done on the actual implementation of these tools, anecdotal evidence suggests that BREEAM has had less impact on construction practice than the promotional literature indicates. Many assessments are undertaken after the initial design stage has already been completed, limiting the scope for introducing new features or securing new materials. Many are treated as a tick-box exercise, bolted on to existing procedures and ways of working. Finally, the process itself remains expensive, making it prohibitive for smaller projects. The NAO estimates that a construction project must cost in excess of £1.5 million to make a BREEAM assessment economically viable (cited in Westminster Sustainable Business Forum, 2008).

In terms of the use of the tool itself, anecdotal evidence points to the extensive use of scoring and gaming (Cole, 2005; Westminster Sustainable Business Forum, 2008) as assessors privilege low cost, high credit features to obtain a desired score. According to Peter Mayer:

> Achieving credits typically, but not necessarily, results in higher capital costs … The trick is to focus on sustainable options that incur little or no cost. (Mayer, 2008)

This logic often leads to privileging inexpensive features over more expensive ones. Prior to 2008, there were no mandatory thresholds and users could distribute credits across the categories as they chose. The result, as Clare Howe, sustainability director of environmental consultant Corporation Green explained, 'was that buildings could obtain a very good or excellent rating without going too deeply into issues such as energy' (cited in Kennet, 2008). Numerous contributors to professional magazines decry the number of points added for adding recycling space and bike racks (Kennet, 2008; O'Rourke, 2009). Others underline the unfairness of a system which gives credit for location, such that sites closer to public transport automatically do better than those further away (Jones, 2008; Kennet, 2008; O'Rourke, 2009). While a number of these anomalies have been addressed in the most recent version of BREEAM, they point to the way in which formal features of the tool encourage certain types of practice.

In summary, the above comments hint at the types of links which a socio-technical analysis of BREEAM might reveal and its relevance for questions concerning the ongoing development of environmental assessment tools, their uptake and the range of stakeholder understandings and concerns and their implications for future developments. Scholars and promoters of environmental assessment tools identify a number of objectives, ranging from the display of environmental performance, to the assessment of environmental impact, to significant market drivers, to the transformation of corporate culture and the integration of the building process (Cole, 2005). While all of these are logically possible, none rests on empirical evidence of actual practices. Empirical analyses of the alternative technical frames and socio-technical networks surrounding the uptake of BREEAM would go far to help clarify who is using the tool, how, why and to what effect.

Discussion

Mobilizing a socio-technical networks analysis of reinforced concrete, BSLink and BREEAM illustrates the types of processes that analytic concepts such as interpretive flexibility and closure or stabilization serve to identify. In all three cases, seemingly stable artefacts proved to be open to multiple interpretations by different users in the same setting or in different settings. In each case, relevant actors had a vision, not only for what the object in question would look like, but for the types of problems it would be used to solve, how it would be used and, by extension, what distribution of competencies or social division of labour it would depend upon and reaffirm. In all three cases, the implementation of the object involved active efforts by key proponents of the object in question to refashion the world—or at least the relevant stakeholders, their interests and practices—to fit with that vision and in all three cases, relevant users either came on board or rejected the new interpretations, roles and practices.

On analysing continuity and change

While socio-technical networks models are often used to explore micro-level dynamics, they can also be used to explore longer term issues concerning continuity and change. In general terms, the strength and scope of ties between objects and actors help to explain the stability or fluidity of specific technologies.

Of the three cases discussed above, that of reinforced concrete offered an example of stability (or at least processes of stabilization), while the two contemporary cases highlighted the fluidity of current technologies. While one could argue that we captured BSLink and BREEAM at an early stage in their development and that they will soon be stabilized, it is equally plausible to suggest that both IT and assessment tools reflect the openness of recent technologies. Rather than settling down into a single use and fixed form, the strength of BSLink may lie in its ability to be different things for different organizations and actors. Similarly, while a number of recent developments would seem to have helped the BRE in its bid to institutionalize BREEAM as the measure of 'greenness', sustainability itself is the object of ongoing negotiations as the regulatory context and discursive content of the goals change. Thus, even if BREEAM does manage to monopolize the assessment of sustainable performance, it will continue to develop, in content and perhaps even in form. Far from discounting the relevance of socio-technical network analysis, these observations re-enforce the call for analytic tools which can capture the multi-vocality and fluidity of technological objects and the effect of socio-technical networks on their interpretation and use.

Another key insight which the exploration of these three cases has revealed is the need to consider the relative strengths and weaknesses of different links within a socio-technical network in holding together or breaking apart associations (Law, 1986). The strong ties are those that account for the ability of proponents of an object to secure their vision. The weak ones underline the potential for resistance, challenge and reformulation. This model, in turn, provides the basis for a sociological exploration of technology uptake which moves beyond technological efficiency or economic advantage to consider the set of meanings, occupational and social interests and material forces that underlie both traditional practices and proposed reforms. It does so, not by presuming that certain professions necessarily and always have certain interests or that certain tools necessarily and always have certain uses, but by exploring the actual network of actors and entities which supports particular practices and the range of meanings, interests and identities which that network affirms.

Thinking about context and power

A socio-technical networks approach addresses a number of theoretical challenges which have been raised recently in the literature on the built environment. In a recent issue of *Building Research & Information* on theory development, a number of scholars underlined the need to integrate material and social dimensions in a single analysis (Hillier, 2008; Moffat and Kohler, 2008; Vischer, 2008). Most of the contributions adopted a macro-level systems approach; socio-technical network analysis, in contrast, offers a practice-based, micro-level approach. By focusing on practices, the approach examines the mutual constitution or co-production of objects and actors, their interests and identities, as evidenced in practices.

This approach, in turn, suggests an interesting refinement of calls for attention to context and social settings (Bresnen and Marshall, 2000; Bresnen *et al.*, 2005; Fernie *et al.*, 2006). Whereas the term 'context' is often used loosely to refer to those entities and influences that tend to be ignored by conventional accounts, socio-technical network approaches reject the use of context as an underspecified residual category and offer a more precise analytic definition. According to the analytic model, when one entity in a network is altered, the other entities in the network and the relations between them are re-adjusted. If this is not the case, then the entity in question is, by definition, external to the network, although not necessarily without influence (Hughes, 1999). This approach is helpful in that it forces the scholar to specify the mechanisms by which particular macro-level factors impinge on everyday practice and to distinguish between those that are co-produced with the activities in question and those that are external to the network (and thus genuinely deserve to be called 'context').

Socio-technical network analysis also offers an alternative way to think about power in relation to both technology and construction practice. In actor-network theory, 'power' is associated with the strength of a network (Callon, 1986; Law, 1986; Callon, 1999). The stronger the links between the entities, the longer and more influential the interpretations, interests, identities and practices which the network secures will remain in their current state and the better they will resist challenges. While certain actors or technologies may be 'powerful' (in the sense of managing to impose their definition of the situation on actual practice and thus on actors and entities), their power resides not in their intrinsic characteristics but in the strength of the network in which they are embedded. One of the advantages of this definition is that it opens the way for a reflection on the conditions for change. Weak links signal the opportunity for change, strong links indicate a capacity to resist.

Conclusions

The socio-technical networks approach we advocate here makes a number of important contributions to construction management research. First, it offers an approach to the study of innovation and change which explores the mutual constitution of both the technical and the social and which refuses any *a priori* assumptions about their boundaries. Secondly, it offers an approach which refuses the analytic distinction between invention and diffusion and instead explores the ongoing development of objects and actors. Thirdly, it provides a framework for the study of differences. Whereas many theories of innovation offer an abstract, acontextual, descriptive model of innovation, social-technical network analysis offers a method to explore variations in the form, meaning and use of formally identical artefacts. It asks how particular artefacts and practices come to take on one form rather than another.

From a policy perspective, the contribution of this type of analysis lies in its analysis of the types of relations that will need to be strengthened and/or transformed for proposed reforms to be implemented. It provides the basis to identify alternative directions for technological development, depending on the types of alliances (and consequent mutual reconstitution of practices, interests and identities) that are established. It also allows an analysis of the meanings, identities and interests which inevitably shape the production of such tools and the practices and wider networks of which they form a part.

This framework offers a flexible way of doing research and analysing technological development, which can draw on a range of theoretical approaches. It can also contribute to ongoing debates within the expanding field of construction management research, as well as to the policy arena. Above all, it represents a coherent and inclusive approach for interrogating the complex realities of interactions between people, artefacts and institutions in empirical settings.

Notes

1. In 1904 Coignet took out a British patent for his system and began construction in the UK. He was soon followed by Considère and Visintini and the Trussed Concrete Steel Co., using Kahn's system (Cusack, 1987; Bussell, 2001).

References

Abbott, A. (1988) *The System of Professions,* University of Chicago Press, Chicago.

Baker, A.L.L. (1956) The growth of the concrete industry. *The Engineer,* Centenary Number, 1859–1956, 179–84.

Bijker, W. (1995) Sociohistorical technology studies, in Jasanoff, S., Markle, G.E., Petersen, J.C. and Pinch, T. (eds) *Handbook of Science and Technology Studies,* Sage, Thousand Oaks, CA, pp. 229–56.

Bijker, W. (2000) The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage, in Bijker, W.E. and Law, J. (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change,* MIT Press, Cambridge, MA, pp. 75–102.

Bijker, W.E. and Law, J. (eds) (2000) *Shaping Technology/ Building Society: Studies in Sociotechnical Change,* MIT Press, Cambridge, MA.

Bijker, W.E., Hughes, T.P. and Pinch, T. (eds) (1999) *The Social Construction of Technological Systems,* MIT Press, Cambridge, MA.

Bowley, M. (1960) *The Construction Industry,* Duckworth, London.

BRE Global Ltd. (2009a) BREEAM assessor manuals, available at http://www.breeam.org/page.jsp?id=109 (accessed 29 May 2010).

BRE Global Ltd. (2009b) The benefits of a BREEAM building assessment, available at http://www.breeam.org/ page.jsp?id=23 (accessed 30 May 2010).

Bresnen, M., Goussevskaia, A. and Swan, J. (2005) Editorial: managing projects as complex social settings. *Building Research & Information,* **33**(6), 487–93.

Bresnen, M. and Marshall, D. (2000) Partnering in construction: a critical review of issues, problems and dilemmas. *Construction Management and Economics,* **18**, 229–37.

Brown, J.M. (2001) W.B. Wilkinson (1819–1902) and his place in the history of reinforced concrete, in Newby, F. (ed.) *Early Reinforced Concrete,* Ashgate, Aldershot, pp. 43–55.

Burrows, D. (2009) Reader's comments, appended to five steps to a successful eco-assessment by David O'Rorke, 23 February, available at http://www.building.co.uk/five-steps-to-a-successful-eco-assessment/3134529.article (accessed 30 May 2010).

Bussell, M.N. (2001) The era of the proprietary reinforcing systems, in Newby, F. (ed.) *Early Reinforced Concrete,* Ashgate, Aldershot, pp. 187–213.

Callon, M. (1986) Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay, in Law, J. (ed.) *Power, Action and Belief: A New Sociology of Knowledge,* Routledge & Kegan Paul, London, pp. 196–233.

Callon, M. (1999) Society in the making: the study of technology as a tool for sociological analysis, in Bijker, W. (ed.) *The Social Construction of Technical Systems: New Directions in the Sociology and History of Technology,* MIT Press, Cambridge, MA, pp. 83–103.

Chandler, A.D., Jr (1977) *The Visible Hand: The Managerial Revolution in American Business,* Belknap Press, Cambridge, MA.

Cole, R.J. (2005) Building environmental assessment methods: redefining intentions and roles. *Building Research & Information,* **35**(5), 455–67.

Cole, R.J. (2006) Shared markets: coexisting building environmental assessment methods. *Building Research & Information,* **34**(4), 357–71.

Crawley, D. and Aho, I. (1999) Building environmental assessment methods: applications and development trends. *Building Research & Information,* **27**(4/5), 300–8.

Cusack, P. (1986) Architects and reinforced concrete specialist in Britain, 1905–08. *Architectural History,* **29**, 183–96.

Cusack, P. (1987) Agents of change: Hennebique, Mouchel and ferro-concrete in Britain, 1897–1908. *Construction History,* **3**, 61–74.

Dammann, S. and Elle, M. (2006) Environmental indicators: establishing a common language for green building. *Building Research & Information,* **34**(4), 387–404.

DEFRA (2007) *Securing the Future: Delivering UK Sustainable Development Strategy,* HMSO, London.

Delhumeau, G. (2001) Hennebique and building in reinforced concrete around 1900, in Newby, F. (ed.) *Early Reinforced Concrete,* Ashgate, Aldershot, pp. 135–53.

Fernie, S., Leiringer, R. and Thorpe, T. (2006) Change in construction: a critical perspective. *Building Research & Information,* **34**(2), 91–103.

Hamilton, S.B. (1956) *A Note on the History of Reinforced Concrete in Buildings,* National Building Studies Special Report No.241-30, HMSO, London.

Harty, C. (2005) Innovation in construction: a sociology of technology approach. *Building Research & Information,* **33**(6), 512–22.

Harty, C. (2008) Implementing innovation in construction: contexts, relative boundedness and actor-network theory. *Construction Management and Economics,* **26**, 1029–41.

Hess, D.J. (1995) *Science and Technology in a Multicultural World,* Columbia University Press, New York.

Hillier, B. (2008) Space and spatiality: what the built environment needs from social theory. *Building Research & Information,* **36**(3), 216–30.

Hughes, T.P. (1999) The evolution of large technological systems, in Bijker, W.E., Hughes, T.P. and Pinch, T. (eds) *The Social Construction of Technological Systems,* MIT Press, Cambridge, MA, pp. 51–82.

Hurst, B.L. (2001) Concrete and the structural use of cements in England before 1890, in Newby, F. (ed.) *Early Reinforced Concrete,* Ashgate, Aldershot, pp. 21–41.

Jasanoff, S., Markle, G.E., Petersen, J.C. and Pinch, T. (eds) (1995) *Handbook of Science and Technology Studies,* Sage, Thousand Oaks, CA.

Jones, W. (2008) Fitzpatrick builds for its green future, 19 November, available at http://www.building.co.uk/fitzpatrick-builds-for-its-green-future/3120900.article (accessed 31 May 2010).

Kennett, S. (2008) Making BREEAM robust, issue 10, available at http://www.building.co.uk/comment/making-breeam-robust/3108657.article. (accessed 31 May 2010).

Kennet, S. (2009) BREEAM and LEED to work together on new global standard, 3 March, available at http://www.building.co.uk/news/breeam-and-lead-to-work-together-on-new-global-standard/3135155.article (accessed 31 May 2010).

Klein, H.K. and Kleinman, D.L. (2002) The social construction of technology: structural considerations. *Science, Technology and Human Values,* **27**(1), 28–52.

Latour, B. (1996) *Aramis, or the Love of Technology,* Harvard University Press, Cambridge, MA.

Law, J. (1986) On the methods of long-distance control: vessels, navigation and the Portuguese route to India, in Law, J. *Power, Action and Belief: A New Sociology of Knowledge,* Routledge, London, pp. 234–63.

Mayer, P. (2008) What it costs: BREEAM – how to get good grades, 25 April, available at http://www.building.co.uk/what-it-costs-breeam-–-how-to-get-good-grades/3111971.article (accessed 30 May 2010).

Moffat, S. and Kohler, N. (2008) Conceptualizing the built environment as a social-ecological system. *Building Research & Information,* **36**(3), 248–68.

Newby, F. (2001) Introduction, in Newby, F. (ed.) *Early Reinforced Concrete,* Aldershot, Ashgate, pp. xiii–xxxv.

OGC (2008) *Sustainable Procurement and Operations on the Government Estate,* Government Delivery Plan, OGC, London.

O'Rourke, D. (2009) How is BREEAM 2008 working out? 5 May, available at http://www.building.co.uk/news/how-is-breeam-2008-working-out?/3139819.article (accessed 30 May 2010).

Parker, J. (2009) BREEAM or LEED - strengths and weaknesses of the two main environmental assessment methods (BSRIA), February, available at http://www.bsria.co.uk/news/breeam-or-leed/ (accessed 29 May 2010).

Pinch, T.J. and Bijker, W. (1984) The social construction of facts and artifacts. *Social Studies of Science,* **14**(3), 399–441.

Rosenberg, N. (ed.) (1971) *The Economics of Technological Change,* Penguin, Harmondsworth.

Rosenberg, N. (1976) *Perspectives on Technology,* Cambridge University Press, Cambridge.

Senker, P. and Simmons, P. (1991) Changing technology and design work in the British engineering industry 1981–88. *New Technology, Work and Employment,* **6**(2), 91–9.

Simonnet, C. (2001) The origins of reinforced concrete, in Newby, F. (ed.) *Early Reinforced Concrete,* Ashgate, Aldershot, pp. 119–33.

Slaton, A.E. (2001) *Reinforced Concrete and the Modernization of American Building, 1900–1930,* Johns Hopkins University Press, Baltimore.

Trist, E.L. and Bamfort, K.W. (1951) Some social and psychological consequences of the long-wall method of coal-getting. *Human Relations,* **4**, 3–38.

Vischer, J.C. (2008) Towards a user-centered theory of the built-environment. *Building Research & Information,* **36**(3), 231–40.

Westminster Sustainable Business Forum (2008) *Costing the Future: Securing Value for Money through Sustainable Procurement,* Final Report of the Westminster Sustainable Business Forum's inquiry into sustainability in public procurement.

Willoughby, M. (2009) Rivals set to challenge BREEAM, 27 February, available at http://www.building.co.uk/news/rivals-set-to-challenge-breeam/3134895.article (accessed 29 May 2010).

Winch, G.M. (2007) The organization of innovation brokers: an international review. *Technology Analysis and Strategic Management,* **19**(6), 747–63.