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THE ROLE OF MIDDLE RANGE PUBLICATIONS IN THE DEVELOPMENT OF ENGINEERING KNOWLEDGE

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ABSTRACT

This paper explores the role of publications in the development of engineering knowledge. Previous studies of scientific and technical publications tend to assume that engineers are like scientists in their use of scientific journals as a means of communicating new technical knowledge. But science differs from technology and we should not expect scientists and engineers to use the same sources of knowledge. We contend that previous studies of publications have been flawed because they ignore other forms of publication more suited to the communication of technical and engineering knowledge. This paper argues that technologists use “middle range” publications to exchange knowledge and explore implications of their technological experiences. By providing more visual images, experience-based reports and background information on technologies and products, middle range publications better reflect the ways in which engineers think and work. They allow for visual conversations and support visual communities. The paper provides a detailed exploration of the role of middle range publications and suggests a framework for future research on patterns of publication by technologists and engineers.

Keywords: engineering knowledge, engineering and design organisations, construction, scientific publications, technical publications, innovation studies

1. INTRODUCTION

Innovation studies have increasingly focused on the way in which firms use and communicate knowledge (Tidd *et al*., 1997; Brown and Duguid, 2000). This paper explores the role of publications in the development of engineering knowledge. It argues that technologists use publications to share experiences and information. Rather than relying on the formal conventions of academic publication, engineers primarily rely on "middle range" publications, such as papers and journals published by industrial associations. Middle range publications are visually intensive, experience-based and provide background information on new technologies and products more so than do academic publications. In order to explore the ways in which middle range publications are used in practice, a set of interview-based case studies of engineering and design organisations in construction were conducted. These case studies show that engineers use a mixture of publication practices. These practices range from publications in academic journals to news articles. The paper explores the reasons for engineers using different forms of publications and the implications of these patterns of publications for the firm. By understanding the way technologists develop knowledge, it is possible to revisit discussions of knowledge management and link these discussions to the role of middle range publications in the development of engineering knowledge.

We contend that previous studies of scientific and technical publications tend to assume that engineers are like scientists in their use of scientific journals as a means of communicating new technical knowledge. However, scientific and technological practices differ. Science is generally concerned with the development of theories of explanation, whilst technology and engineering tends to focus more on theories of action and problem-solving. We should therefore not necessarily expect scientists and engineers to use the same sources of knowledge or to communicate in the same ways. Technical and engineering knowledge may tend to be more tacit and context dependent, than scientific knowledge, requiring different forms of visualisation in explanation. Previous studies of scientific publications have been flawed because they tend to ignore these differences and fail to adequately recognise other forms of publication more suited to the communication of technical and engineering knowledge. By situating our study within the context of the firm, we aim to contribute to an understanding of how firms develop and use technical and engineering knowledge. Detailed discussions of innovation in project-based, service-enhanced firms can be found in Gann and Salter (1998 and 2000).

Our argument is presented in five parts. Section two describes the approach of the study, whilst section three explores the role of publications in the innovation process. Section four describes the findings of the study, exploring the practices of engineers in engineering and design organisations. Section five discusses the new electronic media and communication within and between engineering design firms, and section six presents the conclusions with suggestions for future research.

2. APPROACH AND METHOD

The empirical research for this paper was carried out during a two year period from 1998 to 2000. It involved a series of interview-based case studies of large national and international engineering and design organisations based in the UK. The case studies involved interviews with individuals responsible for technical development (R&D) and support within these engineering and design organisations. The interviews focused on the mechanisms used by engineers to develop and manage information and knowledge. Three in-depth case studies were carried out in participating organisations. These case studies examined the ways in which technical resources are mobilised, fed-back and developed within and between firms engaged in projects. Each case study involved around 25 interviews, each lasting at least one hour. An assessment of the types of activities carried out within the technical support function of these firms was also completed. An attempt was made to understand how central technical support functions within these firms was mobilised and used by project teams. Interviews with project teams within these organisations were also conducted and the experience of project staff was contrasted with those in central technical support. Participating organisations were asked to nominate two projects as examples of firm practices and detailed interviews were carried out on these projects. Individuals working within project teams and technical support were questioned about the way they use information.

The companies involved in this study are all major engineering, design and construction organisations. Most of the group of firms are listed among the 500 largest engineering design firms in the world, several are classified among the largest contractors (ENR, 2000). In total, the collaborators managed almost $3 billion in design work in 1999 and, between them, employed around 30,000 engineers in their design activities.

The approach taken in this paper is similar to that of Veshosky's study of the management of innovative information in US-based construction firms (Veshosky, 1998). Like that study, our research relied on the ability of engineers to accurately describe their practices through interviews. The limited number of organisations who participated in our study places some limits on the implications of the results. Aspects of the findings may also be particular to the construction process. Where possible findings from studies of engineering design in manufacturing and software industries have been included in the analysis to broaden the discussion. The findings of the study are preliminary and further work in this area will be required to draw more general lessons for theory and practice.

3. WHY DO TECHNOLOGISTS PUBLISH?

The increasing concern of managers with knowledge management has tended to focus their attention on the role of new Information and Communication Technologies (ICT), such as intranets and project-based information systems. Academics have also followed this trend and in recent times, with the exception of Hicks (1995), little attention has been paid to the role of publications in shaping the way technologists communicate and develop knowledge. Yet publications remain an important part of the landscape of technological development. Publications are widespread, commonly used and remain an invaluable source of knowledge and information exchange for technologists and engineers. In this paper, we explore some of the different forms of publications and how they shape the development of engineering knowledge.

The role of publications goes to the root of debates about the nature of knowledge and technological development. The starting point has been the distinction between science and technology. De Solla Price suggests that engineers are *papyrophobic*, i.e. they have a phobia about paper. Engineers desire to protect their knowledge (De Solla Price, 1977, p. 561). "(*T)he scientist wants to write but not to read, and the technologist wants to read but not write*" (De Solla Price, 1977, p. 562, emphasis in original). David and Foray support this view, suggesting that the development of engineering knowledge often takes place in a “closed system” (Daivd and Foray, 1995). In his influential study, Allen (1977) also suggested that engineers have little interaction outside their organisation. For example,

> [t]he competitive environment in which [technologists] operate necessitates control over the outflow of messages. The industrial technologist or scientist is thereby essentially cut off from free interaction with his colleagues outside the organisation (Marquis and Allen, 1966).

In comparison to scientists, Allen found that engineers relied on communication inside the organisation as the main mechanism of exchange of ideas and knowledge (1977).

Yet, the preponderance of technical publications suggests that there may be more published communication among engineers than these studies have suggested. Von Hippel (1988) argues that technologists develop informal trading networks for sharing information, experience and problems. In these networks, technologists get to know each other through professional associations, conferences and informal contacts, Von Hippel argues. Technologists build personal and informal expert lists of individuals whom they judge to have expertise and will offer private judgements on areas of knowledge. There is a traded exchange of information within the networks without recourse to market relations (Von Hippel, 1988). Rappa and Debackere found technologists and scientists are often bound together in technological communities. Technological communities are “the group of scientists and engineers, who are working on an inter-related set of technological problems and who may be organisationally and geographically dispersed but who nevertheless communicate with each other” (Rappa and Debackere, 1992, p. 12). Within these loosely coupled technological communities, interdisciplinary groups of practitioners and academics may band together around common interests and/or problems. Publication may provide an entry-ticket into the community (Rosenberg, 1994).

We contend that it is necessary to explore different types of publications and to look at how different industries use publications in order to gain a better understanding of the flow and use of information by engineers and technologists. Academic publications are only the tip of the iceberg of publications used by industry for communicating knowledge, and further research is required to understand the role of publications in the development of technical knowledge. Our study aimed to contribute to this understanding.

FORMS OF PUBLICATIONS

Academic and other forms of publications play a variety of roles for engineers and technologists and within firms. Passman argues they cannot be "simply partitioned on the basis of their function of the type of literature: rather they interact and compete in various ways for the attention of authors and 'users' for the available resources" (Passman, 1969, p. 20). Important publications in the construction industry, and many other industries, are often not considered as "academic". Many types of publications are not included in the Science Citation Index, such as professional association journals, firm journals and industrial association reports. Many of these publications may even be blind refereed and publicly available. They often follow an "academic" style and are sent to public libraries where they are catalogued with other academic journals. It is not simply that these publications have not yet been included in the Science Citation Index, but rather that the forms and role of these publications differs from academic work, although in structure and form they may appear to be very similar[1].

Publications can be seen to be located along a continuum ranging from pure academic fields to those in newspapers and other media. There are many types of publications that can be classified as being in the *middle range* of this continuum. Passman lists different forms of publications:

1. Standard academic journals;
2. Report-based journals or magazines, such as journals of professional societies or *Science*;
3. Commercially-oriented professional journals, such as *The RIBA Journal*;
4. Government published reports or reports by authoritative bodies, such as the Health and Safety Executive;
5. Corporate or non-government organisation reports or journals, such as *The Arup Journal*;
6. Commercially-operated trade journals, such as *Building and Design*;
7. Large-scale subscription journals or magazines, such as *New Scientist*.

Others could be added to this list, including:

8. Product catalogues;
9. Web sites and extranets;
10. Newspapers and other popular media.

[1] Studies of innovation, especially innovation surveys, such as the Pace Study, often fail to make a distinction between academic and trade publications. Firms are asked about the importance of *all* publications, not just academic publications. In this respect, the findings of these surveys may be reflective of the importance of published information in general, rather than academic papers in particular. This point is often ignored in studies

Publications ranging from report-based journals or magazines to large-scale subscription trade journals can be considered middle range publications. Middle range publications may be semi-specialised, that is, they focus on a small, technically interested audience. Many middle range publications may be peer-reviewed, but often they are not. Review processes are often informal and conducted by the editor or funder of the research. There is a widespread belief amongst segments of the academic community that such reports are of “lower quality” than scientific publications. Some may appear “unscientific” in presentation. But appearances can be deceiving and the role of these publications in the innovation process can be greater than commonly perceived, as we will show in the next section.

In order to develop our argument about publications in different industries and to introduce our empirical evidence, we briefly review the innovation process in the construction industry, focusing on engineering and design organisations. The experiences of engineering and design organisations are used as an example of how technologists use middle range publications in the development of their engineering knowledge. This review suggests that technologists do communicate across organisational boundaries and do publish. Professional associations often help to mediate these patterns of communication. Engineers communicate and publish to maintain or gain access to technological communities, and membership in these technological communities helps them to solve problems and update their technical skills and competencies. Middle range publications can also stimulate interest in new technologies.

4. ENGINEERING AND DESIGN ORGANISATIONS IN CONSTRUCTION

The focus of our empirical investigation is on designers in the built environment. In order to create complex, design-intensive buildings and structures, such as the Guggenheim Museum, engineering and design organisations are essential. They provide a wide range of services to the construction process, including design of electrical and mechanical systems, structural engineering and environmental controls. They help to translate the conceptual ideas of architects into physical forms that can be constructed and that can operate effectively. Engineering and design organisations are not merely service suppliers to the industry; they often act as technological gatekeepers for new practices.

of innovation survey results where publications are taken to mean academic publications by the authors (see Arundel *et al*., 1995).

The construction process is largely also project-based. Personnel from independent firms join together in project teams that usually disband at the end of each project. The project-based nature of activities means organisations working in the sector often struggle to learn from project to project. Projects are often one-off and task-oriented. Learning in one project is rarely fed-back to the organisations, as project teams operate semi-autonomously and outside the boundaries of the firm (see Gann and Salter, 1998). Design activities are often undertaken under severe time constraints and this lack of time acts as a barrier to innovation. Veshosky quotes one engineer describing learning in this project-based, time-pressurised environment in construction like "trying to get off a galloping horse" (Veshosky, 1998).

Technical innovation in the design and construction of buildings often involves the need to understand and integrate products, components and sub-systems produced in other sectors. Skills in systems integration is a pre-requisite in the production of high quality and design-intensive buildings and structures (Gann, 2000). Veshosky argues that engineering and design projects are inherently innovative because they involve innovative problem solving. This problem solving takes place under high levels of uncertainty and unique production and organisational conditions (Veshosky, 1998).

Within the design process, there has been a tendency for designers to "re-invent the wheel" on each construction project (Interviews, 1999; see also Busby, 1999). This tendency can lead to erroneous designs being reused and errors repeated (Busby, 1999). Designers were often unable or unwilling to ask for help within or outside the firm. They were more comfortable attempting to solve problems themselves than asking for help. Moreover, since most construction projects involve substantial bespoke design, designers were often not aware that problems they face have been dealt with in earlier projects (Interviews, 1999). Some of the firms studied had extensive programmes aimed at transferring the lessons of past projects to future projects (Interviews, 1999). Interviewees argued that these programmes have had limited success within their organisation. Project teams do not want to advertise their problems within their firm, they suggested. Designers are more interested in creating new solutions to problems rather than recycling old solutions. As Busby suggests, "[t]he self-image of…[designers]…consistently involved creativity – not so much imaginativeness, or novelty, but the job of developing a complex entity from a simple and vague specification" (Busby, 1999, p. 56). Designers did not like to be confronted with efforts that have been wasted and they see rework as being more administrative than technical work (Interviews, 1999).

Constructors often mediate the feedback from the work of designers, and the clients and users of their designs and therefore there is often little interaction between designers and actual users of their designs. This lack of feedback limits opportunities for learning from past projects (Busby, 1999; Interviews, 1999). When feedback is received, it is usually negative and successes are rarely transmitted back to the design staff (Interviews, 1999).

New electronic based knowledge management tools are seen as providing an opportunity to overcome this bias, but take-up of these new tools within the firms we studied had been slow (Interviews, 1999). For everyday problem solving, engineers rely primarily on conversations with their immediate project team. There is a tacit exchange of experience, information and knowledge among members of design teams (Interviews, 1999). Some of this exchange is visual, centred upon sketches. These exchanges are built upon trust and understanding within the design team. Electronic tools do not provide the immediacy or flexibility of these personal, face-to-face exchanges, interviewees argued (Interviews, 1999). Electronic systems may help to support new exchanges within the company, but designers have tended to prefer those they know personally and who are close at hand to help them solve problems (Interviews, 1999).

Within engineering and design organisations, we found that technical activities are divided between project staff and technical support departments (Interviews, 1999). Technical support departments normally operate as the R&D unit of the firm. In each of the organisations we studied, the technical support function of the firm had an active programme to try to manage information more effectively. Unlike traditional R&D units within manufacturing firms, the technical support functions of engineering and design organisations are not primarily responsible for new product development. In design and engineering organisations, the technical support function is primarily responsible for supporting everyday problem-solving project groups (Interviews, 1999). They conduct research on background technical areas to strengthen the competencies of the organisation. They represent the firm on various technical and governmental committees. They act as listening posts on new technologies and help to share information and experience among the firm. Sometimes, technical support is expected to not only provide technical support to projects, but also to train and recruit new staff to the firm. This training function means that technical support staff need to keep up with latest developments in technology as well as regulations concerning safety and the environment (Interviews, 1999).

Members of the technical support function are often encouraged to produce publications and these represent an opportunity to demonstrate the competencies of the firm to a larger audience (Interviews, 1999). They enable staff to explore the implications of project work of the firm. Within engineering and design organisations, many of the participants in development of technological knowledge can be seen as practitioner-researchers (Groák and Krimgold, 1989). Practitioner-researchers are technologists working in industry who are concerned with the specification of design and/or production of buildings in which there is a continuing research and data acquisition function. In some senses, research activities are part of the normal problem-solving activities of their professions. Their research activities may involve using data and outputs of others; specifying research of one's own; and carrying out research in independent laboratories. Practitioner-researchers may or may not be located in research departments, but nonetheless carry out research and development functions. Much of these activities are tacit, embedded in the routines of the construction process (Interviews, 1999). They are rarely measured and therefore tend not to be reflected in research and development expenditures of the organisations within which they are based (Groák and Krimgold, 1989).

A study of the use of information by designers conducted in the mid-1980s by the Building Research Establishment supports the findings of our interviews (Marvin, 1985). The study was based on an analysis of information used by over 50 designers of roofing systems. It showed that design is a non-linear process; designers shift from sketches to specifications through an iterative process of experimentation, feedback and learning. As designs develop, the importance of middle range publications tends to increase. For preliminary sketches, designers relied on past experience to guide their activities. Designers tended to be naturally conservative. They preferred "tried and tested" methods over risky, but possibly, more innovative, options. Before ideas could be committed to paper, designers needed to consult publications. The main literature used by designers was manufacturers' product catalogues and, in particular, the technical specifications of the products. The catalogues were used not only to gather information about the technical characteristics of particular products, but to see the general principles of use of the product. In almost all cases, the technical information provided by manufacturers' product catalogues was inadequate and personal contact with manufacturers was necessary (Marvin, 1985).

Designers in engineering and design organisations tended to rely on personal libraries or those of colleagues close by as the main source of information to support their design activities. Designers' personal collections usually contained manufacturers' product catalogues, textbooks and journals from professional institutions. Most of these publications were less than three years old. Designers had little time in their everyday work schedule for concentrated reading. On average, designers read for two to three hours per week. What reading takes place occurs over the weekends, travel to and from work and over lunches. Designers read professional journals because they provide topical information on the state of the profession. They also liked the design and layout of these publications. They were seen to be easy to read and understand. Since design decisions were normally made under tight time constraints, designers relied on the information that is easiest to access. Informal discussion with colleagues is the main mechanism for finding publications (Marvin, 1985). Marvin and findings from our interviews are supported by the results of De Smet's study of technologists communication patterns. De Smet found that for technologists, the first channel of information gathering is oral, followed by paper and then electronic sources. When technologists do look to publications, their behaviour is improvised, dispersed and at a technically low-level (De Smet, 1992).

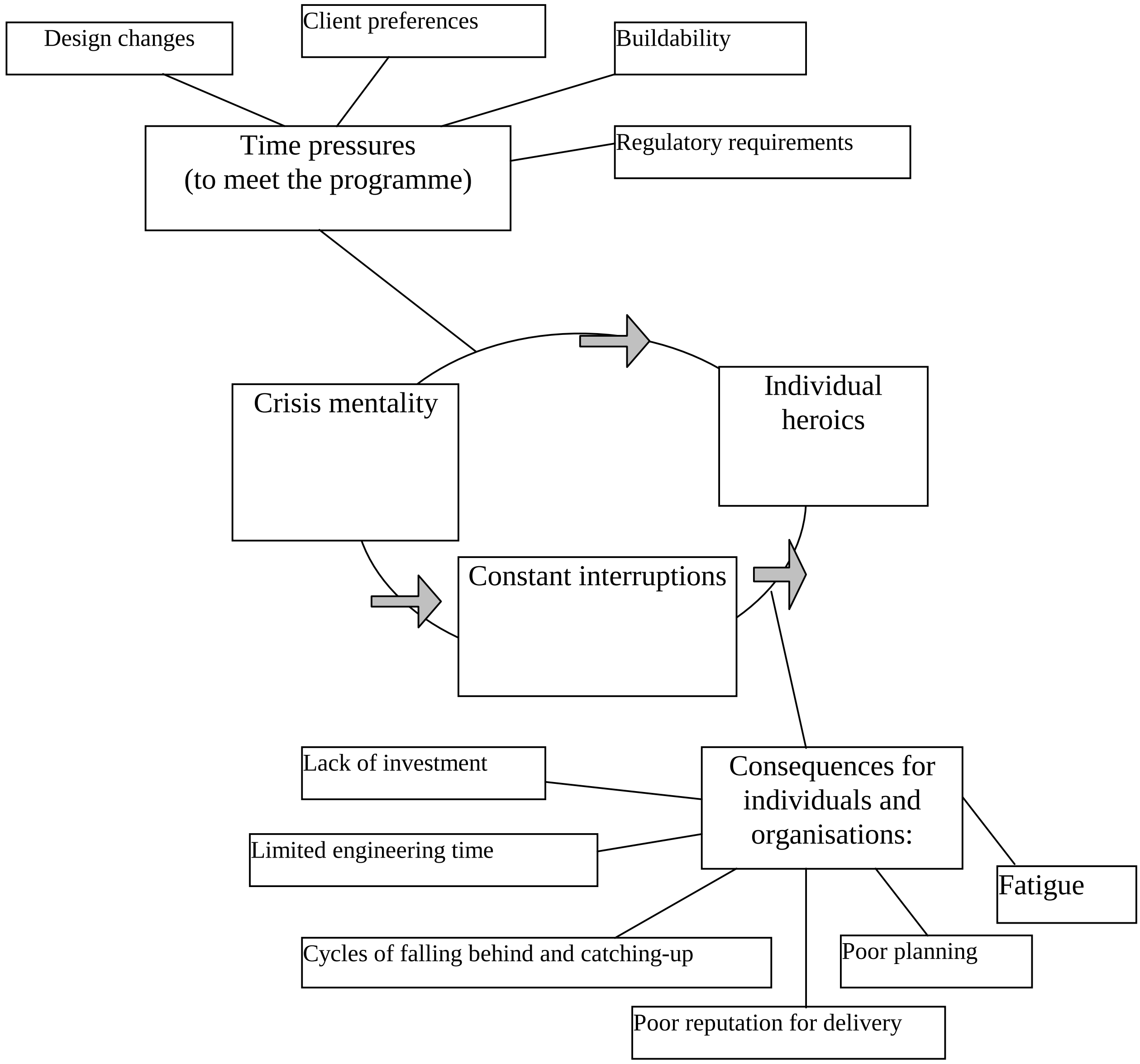
Interviewees suggested that one of the reasons for this pattern of behaviour among designers is that they are often caught in time traps (Interviews, 1999; Perlow, 1999). Perlow's study of software engineers' patterns of work illustrates this phenomenon. With limited time for training, designers were often confronted by steep learning curves. Their "real engineering time" (analytical thinking, mathematical modelling, and conceptualising solutions) was constantly disrupted by interactive activities. These disruptions emerged by attempts to solve problems jointly with others. Almost all of the interactive activities emerge spontaneously. These disruptions left designers with little control over their own work and fragmented their workday in small segments of "real engineering" work. Interviewees for this study argued that these interactions are essential in the design process, however (Interviews, 1999). These interactions allow designers to share experience and help articulate problems and expectations.

Perlow found that designers were often put under pressure to respond to new and urgent requests from management and the completion of these tasks delayed their planned work. Design work often ended up in a state of crisis as many small problems overcame work plans. Designers were rewarded for their ability to make heroic efforts to overcome these crises. Crises created visibility for the designer and allowed them to get noticed by senior managers, Perlow argued. Because designers are constantly confronting crises, they have little time to invest in future work and for reading and writing (Perlow, 1999).

This situation among software designers described by Perlow appears to be similar to problems faced by building designers. In construction, project programmes have strict specified time pressures. Rarely do these programmes have the flexibility to allow for problems arising in the design process. Within the industry, the programme is treated often as a mantra, an organising principle for the social organisation. Changes in the views of clients, regulation pressures and adaptations in designs for buildability place great pressures on engineering and design organisations to respond by altering designs (Interviews, 1999). Like software engineers, building designers are trapped in a cycle of crisis, created by interruptions to their engineering work from colleagues. Design organisations often under-estimate the disruptions to the design process; the need for shared resources; the amount of error and rework; and the amount of design work that could not be anticipated in the programme of work before the project started (Interviews, 1999; Busby, 1999). In these circumstances, there is little time for planning, forethought, training, or even reading.

Figure 1 shows the time crises cycle for designers in the Built Environment. It shows the reinforcing cycle of delay, catch-up, crisis and overwork that characterises the life of designers. Time pressures emerge from changes in designs, client preferences, regulatory requirements and buildability issues. The impact of this cycle of work is a lack of investment in training and skills, limited time for engineering work, continuous cycles of falling behind and catching up, a poor reputation for delivery, and inadequate planning of future work (Interviews, 1999).

FIGURE 1. THE DESIGNER TIME-WORK CYCLE



Source: Developed from Perlow, 1999, p. 58.

When engineers do find time for reading and writing, their approach to publications can be divided between types of activities: competence-building and problem-solving (Rosenbloom and Wolek, 1970). Competence-building reading is when a technologist seeks to add or maintain an underlying knowledge base, whereas problem-solving involves immediate searches for knowledge about pressing, time-dependent problems. Competence-building often involves maintaining membership in technological communities, such as professional associations, through scanning journals and professional newsletters. Competence-building may lead technologists toward academic papers as they seek to strengthen their underlying knowledge base. Problem-based approaches are more direct and lead the technologist to activities of seeking out information to deal with their immediate concerns. This might involve active searches of existing publications for relevant and useful material.

Veshosky found that there were considerable differences between the way project managers in construction use publications with regard to competence-building and problem-solving. In both areas, technologists cited conversations with colleagues and clients as the key source of information for innovation. For competence-building, technologists relied more on trade magazines over professional meetings or conferences. Internal and industry technical reports were frequently cited among respondents. For problem-solving, technologists relied on publications such as product literature, industry technical reports, and professional journals. When engineers did read or scan publications for ideas about innovation, they tended to focus on advertising-support trade magazines rather than professional journals.

Throughout the life of projects, information sources for innovation also vary. Figure 2 shows that in early stages of projects, designers rely on close contact with colleagues and personal resources. As the project develops, external sources become more important. This suggests that in the early stages of project development, tacit knowledge is extremely important, but as the project develops, publicly available information becomes more valuable (Veshosky, 1998). The rise in the importance of public information is related to the need to work with other firms and regulations concerning design and construction (Interviews, 1999). Figure 2 also shows that engineers rely on personal contacts and conversations before using published information, but published information is a valuable resource to them in their problem-solving activities at later stages in the project.

FIGURE 2. INFORMATION SOURCES DURING PROBLEM-SOLVING PROCESSES

Initial sources **Early stages** **Sources for details** **Final sources**

Source: Veshosky, 1998, p. 62.

There are several important reasons why informal communication is important for engineers in the early stages of projects. Wolek has argued that the choice of information sources depends on the complexity of the problem faced. The more difficult the problem, the greater the need for personal contact. Interpersonal communication is more flexible, relevant, interactive and multi-modal (variety in the content of the communication) than formal communication. Informal communication allows for the adaptation of the message to the characteristics of the recipient. Communication can be adapted, modified and evaluated through interaction to suit the interests, background and knowledge of the participants (Wolek, 1970).

Despite these time constraints, publications in middle range journals among design organisations are common. What can explain this need for taking time out, for reading, and for writing? One reason is that for the engineering and design organisations involved in this study, the production of academic and technical papers was seen as part of the pursuit of engineering excellence (Interviews, 1999). Like scientists, technologists also work toward a larger social goal of a professional craft (Interviews, 1999). Within engineering and design organisations, this notion of professional craft is enshrined in the organisational philosophy of the company. For example, Ove Arup, the founder of Ove Arup & Partners, set out the principles upon which his company performs engineering. The first priority of the firm is not profit maximisation, but engineering excellence pursued through the concept of total design.[2] As other historical studies of the engineering profession have shown, social improvement through design has been a central concern of the engineering community since the late 19th century (Ferguson, 1992). Ove Arup & Partners attempts to build on this tradition. Middle range publications are seen to be a way of motivating, retaining and recruiting staff (Interviews, 1999).

Publications therefore play an important role in stimulating engineering excellence by encouraging staff to seek to fulfil engineering's social function, as well as the economic goals of the firm (Interviews, 1999). Several of our research subjects offered rewards for publications. For example, Mott Macdonald offers a £3,000 prize to any staff member who publishes an important paper in an academic journal (Interviews, 1999). This finding contrasts with Hicks who suggests that companies "do not offer rewards for publication as they do for patents, though they take into account publication records in staff reviews" (Hicks, 1995, p. 412). This fact that firms do offer financial incentives for publication does not detract from Hicks' original argument, instead it suggests that many firms recognise the value of publications for the firm. There may be more management of publications within firms than Hicks' had originally suggested.

Table 1 illustrates the role of different forms of publications by categories of engineering knowledge. The categories of engineering knowledge are drawn from Vincenti (1990) and show the elements of knowledge underlying design. We have used the results from our interviews to represent the impact of different publications on each category of design knowledge. Table 1 shows that middle range publications play different roles in the way technologists learn and communicate. Academic journals provide little information about the criteria and specifications of artefacts and practical considerations in design decisions, whereas they provide information about fundamental design concepts and theoretical tools. Middle range publications, from report-based journals or magazines to large-scale

[2] For example, Ove Arup & Partners gives 20% of its profits to a charitable trust.

subscription journals, provide practical and problem-oriented information about the nature of design (Interviews, 1999).

TABLE 1. THE ROLE OF PUBLICATIONS BY DIFFERENT CATEGORIES OF ENGINEERING KNOWLEDGE

		Knowledge categories					
	Publications	Fundamental design concept	Criteria and specifications	Theoretical tools	Quantitative data	Practical considerations	Design instrumentalities
	Standard academic journals	*		*	*		
Competence-building	Report-based journals or magazines	*	*	*	*	*	*
	Commercially-oriented professional journals	*	*	*	*	*	*
	Corporate or non-government organisation reports or journals	*	*	*	*	*	*
	Government published reports		*		*	*	
	Commercially-operated trade journals		*		*	*	*
	Large-scale subscription journals or magazines					*	
Problem-solving	Product catalogues		*			*	*
	Web sites and extranets		*		*	*	*
	Newspapers and other media					*	

Source: Developed from Vincenti (1990).

Why do technologists rely on middle range publications? Passman argues that middle range publications can be more timely, have a broader readership, include larger and more complete methodological statements, and be more user-oriented than academic papers (Passman, 1969, p. 45). Middle range publications may include a discussion of “negative results, that is, theoretical and experimental avenues that were explored but found unproductive for one reason or another – a valuable time-saver for the investigator who wishes to profit from the experience of others” (Passman, 1969, p. 45). Scientific publications normally contain only the essentials of the research, conveying that the researcher had little difficulty reading their conclusions, Passman suggests. In academic publications, information is presented in a very stylised format. Even in closed communities, technical reports are subject to close scrutiny. Studies also showed that close to 60 per cent of technical reports end up as academic papers (Passman 1969, p. 47). Wolek found that the main role of technical literature “is not as a reference source (for problem-solving), but as a primary source of [intellectual] stimulation” (Wolek, 1970).

There are social factors that also explain these patterns of publication. Employees in engineering and design organisations are members of professional associations and/or specialised technological communities, such as acoustics engineering. For example, Ove Arup & Partners has over 6,000 employees of whom around 4,000 are engineers who are members of engineering associations. Publications in the academic and trade press can enhance their personal profile and the profile of their organisation within these technological communities (Interviews, 1999). Professional associations, such as the Royal Institute of British Architects (RIBA), publish journals that are distributed among members of the association. These associations act as colleges and learned societies, where information and experience is shared among members of the distinguished ‘craft’. Debates about methods of practice, new technologies, regulations and government policies often take place in these publications. Technologists rely on these publications to keep them informed of developments in the sector and their field of technology (Interviews, 1999; Becher, 1999). Table 2 contrasts the reasons for publishing in academic and middle range journals.

TABLE 2. THE REASONS FOR ACADEMIC AND MIDDLE RANGE PUBLICATIONS

Academic papers	Middle range publications
• Regulatory agency may require or encourage publication • Indication of quality in scientific work • Desire to see staff gain higher educational qualifications, such as PhDs, through publications • Generate interest in new technologies or product • Raise corporate image or signalling • Aid networking and facilitate co-operation	• Membership professional association • Marketing • Indicators of technical capability • Aid networking and facilitate co-operation • Improve communication among various parts of an organisation or technical community • Part of the firms' knowledge management strategy • Indicate technical features of products • Indicate application of products or techniques • Present visual images • Exchange experiences • Contribute to professional responsibilities • Learn from past projects • Source of intellectual stimulation

In our interviews, we found that the difference between what appears in the middle range publication and an academic publication can be essential to the building designer. Technologists' communication habits are based on personal experience and verbal communication (Interviews, 1999; Passman, 1969; Henderson, 1999). Conversations with colleagues, informal meetings, and first-hand experience often provide technologists with the rules of thumb necessary for technological problem-solving (Interviews, 1999). Interviewees argued that the informal style and problem-oriented focus of middle-level publications is closer than a stylised academic paper to the way technologists work. Technologists also rely on non-verbal tacit understandings, only partly formed and often difficult to communicate. The informal style of middle range publications allows the technologists to express themselves without being encumbered by the demands of academic discourse (Interviews, 1999).

In her study of design communication, Henderson (1999) reached a similar conclusion. She showed that the design engineers rely on visual communication. Sketches provide opportunities for engineers to communicate their tacit understandings of artefacts. They can use images where no words will suffice, she suggested. They tell stories when data is scarce and they can express judgements based on tacit experience, rather than as a product of careful, neutral reflection on empirical data. Middle range publications are usually visually complex, providing pictures or drawings of technological artefacts. The process of learning for technologists often depends on the visual interpretation of artefacts (Vincenti, 1990; Ferguson, 1992; Henderson, 1999; Constant, 2000).

Middle range journals support the development of *visual communities* of practitioners. A visual community is a community of practitioners who rely on exchanges of visual experiences to share and develop knowledge. In our interviews, we found that drawings and pictures in middle range journals allow the interviewees to draw similarities between divergent artefacts, developing new combinations or uses of existing artefacts or technologies (Interviews, 1999). They allowed for visual thinking. Ferguson suggests this is so because engineering knowledge is located in the "mind's eye":

> Many features and qualities of the objects that a technologist thinks about cannot be reduced to unambiguous verbal descriptions: therefore, they are dealt within the mind by a visual, non-verbal process. The mind's eye is a well-developed organ that not only reviews the context of a visual memory but also forms such new or modified images as the mind's thoughts require…The engineering designer, who brings elements together in new combinations, is able to assemble and manipulate in his or her mind devices that as yet do not exist (Ferguson, 1992: xi).

Another possible explanation for our interviewees need for visual communication was the role of pattern recognition. Nightingale suggests that "[l]earning is not just getting more information, as it involves recognising patterns and connections between our memories" (Nightingale, 1998: 693). Visual images stimulate pattern recognition and allow the technologists to see beyond the "flatland" of academic papers (Tufte, 1982). In a similar finding, Tufte suggests that visual images are instruments for reasoning about complicated quantitative information. They help to "describe, explore, simplify and summarise complex sets of information" (Tufte, 1983: 3). They encourage the eye to compare different sets of phenomenon. They help to "*reveal* data". For the technologist, they help to make complexity accessible to the reader (Tufte, 1983: 191).

As part of the visual intensity of middle range journals, graphical representation presents an image of an artefact. Interviewees argued that for them to develop artefacts, graphical representations are essential for turning ideas into reality. For example, interviewees in Ove Arup suggested that the construction of the Sydney Opera House was held together by Utzon's original sketch (Interviews, 1999). Stetches, such as Utzon's, allow the designers involved in the project to make their concepts communicable and once the concept was communicable, it was possible for it to be evaluated and implemented. Through representations, it is possible for the technologist to explore and bring out different features of artefacts, interviewees argued. They showed "a range of not necessarily obvious things which may nonetheless be extremely interesting and even important" (Groák and Krimgold, 1998, p. 52). These representations allowed them "to investigate, define, refine and present ideas" for artefacts (*ibid.*, p. 58).

The development of new forms of visualisation has expanded the potential for engineers to develop new combinations of artefacts (Ferguson, 1992; Henderson, 1999). An example of the importance of visual thinking in engineering design is Ove Arup & Partners' picture database. In order to facilitate visual communication, Ove Arup & Partners maintains a visual database of building and structures. This database is available to all members of the firm and operates a visual record of engineering experience. It is used extensively and allows engineers within the firm to see the artefacts of past projects (Interviews, 1999).

In order to support visual communities and middle range publications, engineering and design organisations often have their own journals. These journals may be used for internal communication, but can also be made publicly available. They are often refereed internally within the firm. For example, Ove Arup & Partners operates its own journal and encourages its staff to publish the findings of their work in it. It believes that lessons can be learnt within the firm and be demonstrated to others in the industry (Interviews, 1999). *The Arup Journal* is widely available in UK public libraries and is peer-reviewed within the firm. It contains articles from Arup staff and project partners. Since Ove Arup & Partners has over 6,000 employees and operates in 77 countries, *The Arup Journal* attempts to link these diverse activities. The publication of *The Arup Journal* outside the firm also enables the firm to demonstrate its capabilities to customers, competitors, and collaborators. *The Journal* thus plays the role of both an internal management tool and an external marketing device (Interviews, 1999). Other firms in the sector also have internal firm journals. For example, WS Atkins publishes *Innovation* which provides information on areas of the firm's technical competencies. Unlike *The Arup Journal*, it is primarily designed for information sharing and marketing, and does not follow the model of an academic journal, although it is available outside the firm (Interviews, 1999).

Table 3 explores the different forms of publications and the benefits they provide to technologists. It is based on the findings of the interviews across the firms involved in the study. It shows that all forms of middle range publications are timely and user-oriented. Visual images are usually concentrated in commercial-oriented professional journals and corporate reports. Negative results also usually do not appear in academic articles, product catalogues, web sites and newspapers. Table 3 also shows that the core benefits of middle range publications are timeliness, user-orientation and visual images. All forms of middle range publications share these features.

TABLE 3. THE BENEFITS OF DIFFERENT FORMS OF PUBLICATIONS FOR TECHNOLOGISTS

	Benefits of Publications					
Publications	Timeliness	User-oriented	Visual images	Negative results	Broad readership	Methods
Standard academic journals						*
Report-based journals or magazines	*	*	*	*	*	**
Commercially-oriented professional journals	*	**	**	*	*	*
Corporate or non-government organisation reports or journals	*	**	**		*	**
Government published reports	*	*		*		*
Commercially-operated trade journals	*	**	**	*	*	*
Large-scale subscription journals or magazines	*	*	*	*	**	*
Product catalogues	*	*	*			
Web sites and extranets	**	*	**		*	
Newspapers and other media	**	*	*		**	

5. NEW ELECTRONIC MEDIA AND ENGINEERING COMMUNICATION

With the development of the World Wide Web in the late 1990s, the opportunities for technologists to communicate through electronic publications would seem to be greatly enhanced. David and Foray have suggested that new forms of information technology may be changing the way technologists communicate, lessening the need for personal interaction and enhancing the ability of technologists to codify their knowledge set (David and Foray, 1995). This process of codification suggests that technological knowledge can be more widely diffused than had been possible previously. There is, however, little empirical evidence about shifts between digital and paper-based publications in the way technologists gather information for their activities. The evidence available suggests that although digital publications can have many benefits for enhancing communication among technologists, paper-based publications are still extremely common in many technological communities (Brown and Duguid, 2000, Court *et al.*, 1997).

In our research, we have found that many engineering design organisations still depend on paper-based libraries as the main form of information support for technologists (Interviews, 1999). Technologists in the built environment collect images from product catalogues and middle range journals to trigger learning and pattern recognition. Digital publications do not yet offer the same range, experience or depth of understanding, although this is changing rapidly (Interviews, 1999).

Moreover, across engineering and design firms, there is considerable variation in IT-systems and project information and these variations limit the development of electronic information sources. Differences in IT-systems emerge from the decentralised nature of production. Project teams may adapt their computer systems in order to co-ordinate activities with other firms with whom they collaborate on specific projects. Regional and national offices may use different systems as many IT decisions are decentralised. The development of integrated project information is also complicated by this decentralisation. Project teams usually control their own project information. Little information from these projects is kept at corporate level, except the financial performance of the project. Attempts have been made at centralising these functions, but these attempts have come up against corporate traditions, incompatible IT systems, and high levels of decentralised decision-making (Interviews, 1999).

The experience of engineering design firms in the use of Intranets provides another note of scepticism about the current ability of information technology to alter the quality of communication among technologists. In theory, the development of intra-firm Intranets provides a new mechanism to support corporate publication. Intranets have been seen to offer the opportunity to firms to improve their management of knowledge by allowing individuals to share information within the firm more easily. Yet, firms in the construction sector often struggle to fill their Intranets with useful information (Interviews, 1999). Usage patterns of Intranets vary considerably among these firms. In order to increase usage rates, firms have launched on-line journals where project staff can share experiences (Interviews, 1999). This represents a new form of intra-firm publication, but uptake of these new forms of publication has been patchy in many of our research subjects (Interviews, 1999).

Another approach to the expanding use of Intranets and to developing corporate publishing is to develop project databases. Unlike traditional project databases that rely on engineering and financial performance data, these databases tell the story of a particular project. Engineers browse these project stories to understand both the technical and social learning that may or may not have taken place on a project. For example, Kvaerner Technology's project database contains information on the technical features of new piling equipment as well as information about hotels in Cairo (Interviews, 1999). The preparation of these project databases is a very time-consuming and costly task. In effect, the firm is forced to develop an electronic book on the project. These project history databases also tend to be completed after the project and therefore rarely reflect the non-linear nature of engineering design decision-making. Unlike *The Arup Journal*, Kvaerner does not make project databases available outside the firm. It sees this database as a form of internal firm knowledge management, rather than a traditional publication.

It is also possible to find more and more technical publications by engineering and design firms on their Web sites. For example, Parsons, a leading US-based design engineering firm, offers over 3000 technical papers on its Web site. These papers cover the range of the firm's technical competencies (www.parsons.com).

With the advent of new forms of publications, such as Intranets, web sites and project databases, the traditional model of paper-based publications may be under increasing strain. Paper-based publications still have many advantages over other forms of digital publications for technologists, however (Brown and Duguid, 2000). They are widespread, accessible and well-known. Brown and Duguid argue that paper-based publications provide validity and instrumental weight to text. In some senses, they help to structure society by creating shared texts among technological communities (Brown and Duguid, 2000).

New digital media can allow for greater representation of artefacts and of the process by which these artefacts were constructed. In the long run, they may prove to be a more useful way for technologists to communicate. Yet, at the present time, paper-based publications still proliferate among designers in the built environment. Future studies of the communication practices of technologists need to explore shifts in media of exchange and the impact of these mechanisms on changes in communication.

The use of information technologies for increased communication among technologists does not, however, have to mean, as David and Foray have suggested, that there is a wide spread codification of knowledge among technologists (David and Foray, 1995). More than likely, new information technologies will lead to new forms of publications, better able to express the technologists understanding via complex visual images. Yet experience in engineering design organisations suggests that these publications will not serve to lower demand for personal interaction. As Hicks has suggested, publications do not act as a substitute for personal interaction, but rather they act as a handmaiden for newer, higher levels of personal communication (Hicks, 1995). Our evidence suggests that new forms of IT-based publications will develop in parallel to more traditional forms of paper-based publications (Interviews, 1999). The two forms of publications will co-exist over time, with designers making choices between the two media on the basis of ease of use, experience and preference. Designers will continue to use mixed practices, shifting between both electronic and paper-based systems of publications (Henderson, 1999).

6. CONCLUSIONS

In this paper, we have analysed the role of middle range publications in the development of engineering knowledge. We have argued that middle range publications play an important role in shaping the way engineers share and communicate information. They offer opportunities for professional and technical exchanges via personal stories and visual images. Despite Allen's argument that technologists operate in closed systems, we find considerable evidence of open debate and disclosure among technologists in construction.

Some of the features of this openness may be special characteristics of the construction sector where there is a high degree of professional association membership, the importance of government regulation, the dominance of bespoke products and the widespread practice of multi-firm project teams. Where firms compete on the basis of more standardised products; the need for secrecy may be greater. But the increasing technology-based nature of innovation suggests that these patterns of publication and exchange are, and could even become more, common across a number of sectors. Why would this be the case? The need for technologists to be "in the know" and their need to share information and experience via images and stories remains undiminished. Middle range publications are among the best places to have these forms of technological exchanges.

Our findings led us to the conclusion that, in future research exploring the role of publications in innovation, it is necessary to explore the role of different types of publications in the innovation process. Our study also shows that firms can benefit from publications in middle range journals. Firms need to create space and opportunities for their employees to share information about products and technologies from outside their organisation.

The widespread adoption of new electronic media, such as Intranets, Web sites and Extranets, offers opportunities for firms to develop new forms of electronic publications that more closely represent that visual thinking of technologists. There is little evidence that paper-based publications will decline as a result of these new developments. As Brown and Duguid argue, the paperless office was a dream of the 1970s that never came to fruition (Brown and Duguid, 2000). Our research suggests that papers remain an essential part of the way engineers communicate through sketches and visual thinking. Middle range publications support this visual thinking by helping to support visual communities, creating shared images and models.

The rise of new virtual communities of technologists who share experience, software and practices on electronic notice boards complements the role of middle range publications (Steinmueller, 2000). Middle range publications in the construction sector have used their web sites to support links between various actors within the sector, highlighting the competencies of different firms and the use of new technologies in projects. In some respects, these new virtual communities are simply an extension of the middle range publication, offering similar opportunities for exchange and debate. Many of these new electronic exchanges, however, lack the authority of more traditional forms of middle range publications. More research is needed on how these new emergent forms of communication are being developed and used.

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