TECHNOLOGY TRANSFER IN CONSTRUCTION: LEARNING FROM THE MANUFACTURING INDUSTRY

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The construction industry has adopted several techniques from the manufacturing industry; these include lean production and just-in-time delivery methods. This demonstrates learning between industries which may be extended to the area of technology transfer. The opportunities for learning from manufacturing's technology transfer practices are based on the constant transfer of new and partially developed technologies from outside the firm into the product development process and the shared characteristics between the industries. The research described in this paper aims to investigate the approaches to technology transfer in the manufacturing sector that may be applicable to multi-national construction projects. A series of detailed semi-structured interviews with four large manufacturing companies in the UK was conducted. The results suggest that manufacturing and construction have similarity in terms of the drivers for technology transfer and the process of transferring technology. The construction technology being transferred highlight significant similarity within two companies. The transferred technology includes the methods, resources and work tasks. Possible lessons that can be learnt from manufacturing include the development of technology transfer goal, conducting resource planning and development of a transfer programme.

Keywords: construction, learning, manufacturing, technology transfer.

INTRODUCTION

Flanagan (2002) highlighted the global drivers of change for construction sectors around the world. The drivers include the growing importance of technology, knowledge and skills of all business, and the acceleration of technological change. Construction organisations are forced to adapt to these changes. Technology transfer has the ability to encourage potential developments and grow knowledge capabilities since much new knowledge is created outside organisational boundaries (e.g. between organisations and disciplines) (Quintas, 2005). The construction sector has adopted many concepts and principles from the manufacturing industry such as Toyota's lean manufacturing system with techniques such as just-in-time (JIT) (Jorgensen and Emmitt, 2008). This is due to the view of construction as a project-based production system. Construction and manufacturing products can be seen as both complex artefacts (e.g. a bridge or a car) and commodities (e.g. factory produced house or a kettle) (Kieran and Timberlake, 2004). Kagioglou *et al.* (1998) stressed that new

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product development relates closely to construction and building since it concentrates on the development of an idea, need or client requirement for the final commercialisation of the product. The view reflects the opportunities for learning from manufacturing as the industry is constantly looking for new and improved products, materials and/or processes. This involves the transfer of new and partially developed technologies from outside the firm into the product development process (Green *et al.*, 1996). This demonstrates manufacturing industry's drive to actively engage and enhance technology transfer.

With respect to the similarities and differences between manufacturing and construction (refer to Table 1), the interdependence between parties shows that construction does share characteristics with manufacturing. Construction parties include architects, engineers, contractors, subcontractors and suppliers. The requirement to complete a construction project to meet the client's expectation demand the cooperation from all parties either local or foreign companies. Construction technology may be transferred between foreign and local companies such as through joint ventures, which may either be project specific or of a longer term nature. Despite much research and application, technology transfer in construction shows the need for improvement (e.g. transfer planning and monitoring, and technology that match the buyer's ability to absorb and adapt into its existing systems) (Ofori, 1994).

Table 1: Similarities and Differences between Manufacturing and Construction

	Manufacturing	Construction
Similarities	The product development involves a number of specialists and functions (e.g. designers, surveyors, marketing, stress analysts) and design-build reflects the product development potential in construction;	
	The building or product can only be successful if all external (suppliers and consultants) and internal resources are utilised and co-ordinated effectively; and	
	The end product is handed over to the customer/client and provisions are made for future support.	
Differences	The new product development activities in the manufacturing industry are coordinated, managed and controlled based on a common framework; and	The construction processes execution are unrepeatable since the industry uses ad-hoc methods resulting in the same mistakes occurring time after time; and
	Manufacturing fabrication mostly occurs off-site in factories dedicated to the production of integrated component assemblies called modules or chunks.	Buildings continue to be assembled largely piece by piece on site (the final point of assembly).

(Source: adapted from Sanvido and Medeiros, 1990; Kagioglou et al., 1998; Ballard and Howell, 1998; Kieran and Timberlake, 2004)

Based on the above discussion, there is a lot that can be learnt from the manufacturing industry. This paper presents a series of case studies on technology transfer practices in manufacturing organisations and highlights a number of potential lessons that can be learnt from the manufacturing sector. Section two of this paper introduces technology transfer drivers, types of technology transferred, the transfer processes and challenges in transferring technology. Section three provides the methodology and technique employed in this research, and section four examine the findings of the data

collected from interviews. Conclusions and the way forward are presented in section five.

OVERVIEW OF TECHNOLOGY TRANSFER

Technology Transfer Drivers

Technology creates wealth and improved the quality of life (Abetti, 1989). Kremic (2003) established that principally organisations are in profit making for its owners for participating in technology transfer. Secondary goals include building new business, creating competitive advantage, and increasing reputation and image, reducing in technology acquisition costs and seeking to develop research and development networks (Keller and Chinta, 1990). Ofori (1994) listed several factors that drive construction technology transfer. These include changes in the nature of the buildings and works demanded by clients, the increase of scientific and technological knowledge within or outside the industry, shortage of specialise resources in more complex projects, and to upgrade the construction industry. Whilst, in the manufacturing industry, technologies may be transferred as a result of new product development, rapid increases/decreases in demand for the firm's products, the need to streamline costs and to improve product quality, and changes in process technology (Efstathiades *et al.*, 2002).

Technology Transferred

UNCTAD (1985) defined technology as "systematic knowledge for the manufacture of a product, for the application of a process or for the rendering of a service." Similarly, Tatum (1987) see construction technology as the combination of construction methods, construction resources, work tasks, and project influences that define the manner of performing a construction operation. In addition, Boyer *et al.* (1996) provide examples of manufacturing technologies such as computer-aided design, manufacturing and engineering, and manufacturing resource planning. This suggests that technology can be divided into two aspects: (1) skills, abilities, knowledge, systems and processes often labelled as the 'soft' aspects; and (2) the 'hard' aspects that include the transfer of actual machinery and equipment. Nobelius (2004) described that the technology intended for transfer may be represented in different forms. For example, a blueprint, prototypes, test methods and results and/or intensive communication between involved parties.

Technology Transfer Processes

The technology transfer processes consist of a series of steps that assist the adaptation of new technology within an organisation. UNCTAD (1985) reported that technology transfer processes consist of 5 stages: 1) assessment; 2) selection; 3) adaptation; 4) development; and 5) use of received technologies. The assessment stages involve a process whereby an organisation searches for a matching technology and donor. A process whereby an organisation decides that both the donor and recipient have the skills, motivation and resources to make the transfer succeed formed the selection stage. The recipient organisation captured the knowledge associated with the technology and utilises the knowledge to meet their own needs represent the adaptation and development stages respectively. The final stage comprises of a process whereby the recipient produces a new product or a series of related products after completing the first four stages of technology transfer process identified earlier. The process of technology transfer is unique to each transfer project. However, Major (1999) suggested various technology transfer were identical under most of the

technology transfer processes. Goldhor and Lund (1983) studied the transfer of a text-to-speech reading machine between Natural Language Processing Group (NLPG) and Telesensory Systems Inc. (TSI). The transfer presented an example of the overall technology transfer processes. The summary of the transfer were as follows:

- Assessment: TSI concluded that they have to develop a reading machine. They are aware that there were many speech synthesis projects around the world.
- Selection: TSI believed that the NLPG text to speech technology was the best advanced technology at that time. Initial discussions took place when TSI received a visit from Professor Allen covering the potential of NLPG's software and hardware to produce the reading machine, licensing arrangements, the funding and the expertise required at TSI.
- Adaptation: TSI visited NLPG where a demonstration of the first version of the system was made and a talk on the new text-to-speech system was held. The agreed software was transferred to TSI soon after the formal visit. An exchange of staff between TSI and NLPG was arranged during the transfer to transform the research software to production software.
- Development: Since TSI completed the text-to-speech system, the work continued to improve the developed system and integrate the system as part of the whole product, the reading machine.
- Use: A prototype of the reading machine was successfully completed in accordance with the planned activities.

It is evident that there are challenges encountered at various stages of the technology transfer processes; these will be discussed under the following sub-heading.

Technology Transfer Challenges

Challenges in the transfer of technology between TSI and NLPG include the complexities of NLPG's research software to be transformed into production software. As a result, TSI's management has seriously discussed to abandon the transfer project. However, TSI decided to continue with the transfer in order to acquire the most advanced technology and to protect their reputation. Other challenges include the absence of written agreements, although terms such as licensing agreement and program for transferring the Modular Speech System (MSS) are raised by NLPG (during the pre-negotiating meeting) and TSI (during TSI's visit to NLPG). The support from NLPG to TSI was very minimal since few visits were made during the transfer. In addition, the purpose of their visits were to work on their own system because the system was not fully developed when it was transferred to TSI. The amount of effort put in by TSI to complete the project was also taken too lightly. The project leader was not appointed and there was a shortage of speech expertise within TSI to overcome the MSS's weaknesses.

In summary, the above challenges can be summed up into the three categories identified by Guilfoos (1989). The categories are technical, regulatory and people. NLPG's complex and incomplete software was technically challenging. Technical challenges include technical risk, lack of operational test data, defined requirements and low understandable technology. The regulatory challenges are concerned when there is a need to have the technology meet existing government specifications and when the organisational specifications (e.g. businesses position or setting) are not compatible with the new technology or the process of transferring technology. Thus, the lack of TSI's organisation setting (e.g. transfer agreement, procedures or programmes) to receive the technology are categorised under regulatory challenges.

Finally, most challenges come from people involved in the transfer process. These include the low level of participation, poor communication and poor motivation during the transfer.

Hence, there is a need to explore in more detail, through case studies, the technology transfer practices adopted by the manufacturing companies based on: (1) the challenges to technology transfer, and (2) the opportunity of learning from the manufacturing technology transfer that have been well established and have some applicability to the construction sector. As a result, the case studies seek approaches that can be used to facilitate/improve the technology transfer in multinational construction projects.

RESEARCH METHOD

The technology transfer practices of manufacturing organisations have been investigated in four UK case studies. The organisations that were observed were chosen based on (1) active involvement in research and development (R&D) activities; and (2) the manufacturing operation forms a key part of the company's businesses. This research adopts a semi-structured interview approach to allow specific topics to be covered, but with sufficient flexibility to explore issues as they arose during the discussion. The interviewees were selected from the R&D team that manage technology transfer projects. Their extensive knowledge covers the overall technology transfer practices in their own businesses. Table 2 summarises participating companies and interviewees.

Table 2: Companies Overview and Interviewees Details

Company	Manufacturing industry category	2008 Annual Turnover (£ billion)	Interviewee	Position	Total years of working experience
A	Pharmaceutical	31.6	Interviewee A	Director of Process Engineering	33
B	Pharmaceutical	24.4	Interviewee B/C	Open Innovation Manager/Academic Liaison	16/33
C	Aerospace and Defence	18.5	Interviewee D	Project Manager	23
D	Aerospace and Defence	9.1	Interviewee E	Team Leader Cost Modelling Strategy	24

The case studies explored the following research questions: 1) What are their drivers for technology transfer? 2) What technology is being transferred; and 3) How did they transfer it? and 4) What are the challenges and strategies adopted in transferring technology? The results of the case studies will then be compared to the findings in prior research on construction technology transfer. The results therefore create a better understanding and justification of what can be learnt from the case studies.

CASE STUDY FINDINGS

The findings of each case study are discussed in four themes which were reflected in the interview questions. These include the goals of technology transfer; technology transferred; technology transfer processes; and technology transfer challenges and the strategies adopted. The case studies revealed that there are similarities between

Companies A and B; and Companies C and D. The discussions on three out of four themes would be between these two groups. However, one theme (challenges and the strategies adopted) will be discussed based on individual companies.

Drivers to Technology Transfer

The case studies identified the drivers to technology transfer are competitive advantage and to create profit (Companies A and B). The other companies aim to improve technological capability. Companies A and B venture into technology transfer in order to generate value from the product produced, whilst Companies C and D are more directed to increase technological capabilities within the company.

Technology Transferred

The technology transferred to Companies A and B was a new product (which involves patents or processes); and for Companies C and D, their technologies were in the form of a software, tool, method or product. Companies A and B ultimately strive for a single purpose (product), while the other two companies targeted high-quality technologies such as casting technology and process modelling to improve manufacturing techniques.

Technology Transfer Processes

Companies A and B shared similar approaches in the process of transferring technology. A transferor is identified through searching for people with specific technology based on internal and external networks or a company that specialised in specific technology. New technologies may also be brought in by other parties (e.g. external organisations or the company employees in other geographical locations). The transferor may either be an individual inventor or large companies; the transferor will be selected based on a technology that matches the company's strategy, the technology (e.g. protected by intellectual property right) and transferor background. Technology that involves licensing will be transferred and the technology will be absorbed within the company during the development of that technology. The company may buy an entire company and their employees will be absorbed into the company's existing facilities. The technology is adapted by incorporating the technology into an existing product or covered in the company's branding. The techniques adopted for technology transfer are face-to-face interaction, recruitment (if involving acquisition) and post project reviews. Intranet and groupware are also used for transferring technology. Companies C and D's technology transfer projects are mainly from universities through the establishment of Research Centres (RC). Each RC addresses a key technology of engineering disciplines ranging from combustion and aerodynamics to manufacturing technology. RCs provide a highly targeted, co-ordinated centre to conduct long-term funded research programmes. The RCs employed world-class academics and is supported by research associates, students and technicians that can be considered as an extension of the company's employees. The technology is transferred to Companies C and D when the research projects are completed and the key employees have decided that it would become part of the company's processes and/or product. The technology is assimilated within the company through its infrastructure, processes (e.g. methods and procedures), knowledge bases (e.g. for design, manufacturing or support), and software (e.g. computing portfolio fully accessible to users). The techniques for transferring technology in Companies C and D are frequent face-to-face meetings, recruitment, apprenticeship and mentoring. The use of tools includes intranet, extranet and data and text mining.

Overall, Companies A and B adopted all the stages of technology transfer starting from the identification of transferor to the adaptation of technology. However, Companies C and D seldom engaged in identification and selection of the transferor was based on the close relationship with the transferor (RC) themselves. The reasons for the differences may be due to the vast opportunities to search for new technology outside Companies A and B organisational boundaries; whilst Companies C and D recognised that their expertise is mostly located in universities.

Technology Transfer Challenges and Strategies

Company A:
The challenges faced by Company A are "not invented here syndrome" in which sometimes employees felt threatened by an external technology, a "different" technology that is incompatible with existing business model, and differences in business culture between the external partners, companies and universities. Strategies adopted to overcome this include constant communication and celebrating the achievement of successful technology transfer projects. Technology transfer requires the management of people in order to have their support and make them part of the process. Principally, this is achieved through good management processes. An adopted process is called Want, Find, Get and Manage (WFGM). The R&D team identify what the company wants and what the company is looking for. Then the team finds and gets the identified technologies. The team then formulates appropriate agreements and proceed with full information exchange to obtain that technology. A programme will be developed as the idea/technology moves through the development stages; this is highly individual. The technology transfer team roles and responsibilities are clearly defined in four themes: Responsible, Accountable, Collaborate and Information (RACI) in accordance with the Technology Transfer Package. The Technology Transfer Package seeks to illustrate the company's ways of working with as much clarity as possible, enabling the team to apply them consistently across the whole transfer duration. Thus, in turn, it eliminates any disagreement occurring during the process of transferring technology.

Company B:
Company B challenges mostly involve people and include getting commitment, resources and support from its staff. The company strategies emphasise project management and planning, employ committed and trained staff, and having a single purpose/goal. Company B has auditable policies and procedures. These include a Standard Operating Procedure (SOP) for technology transfer between internal departments or external to the company. Quite simply, a SOP specifies what should be done, when, where and by whom. Technology transfer's SOP cover from the identification of technology to the adaptation stage. As a result, the company would have a team that designs and develops the technology or the process. High commitment and support would flow throughout the technology transfer project (e.g. the manufacturing team received technical support from R&D) and all the information required will be passed to the people who are going to use it. A clear and at the right priority (among other goals or works) of technology transfer goal/objective is required in getting the stakeholder support in order for them to "release" their employees from other work to achieve successful technology transfer.

Company C:
Lack of trust posed one of the main challenges for Company C. Other problems are lack of commitment, communication, and motivation. Several strategies have been

adopted; these include identifying the technologies required and its benefits to the organisation, fully understand the transfer process to avoid surprises, establishment of ownership, making sure that Intellectual Property (IP) is protected through adherence with regulation, and access to information is given to the people involved in the project.

Company D:
Technology transfer challenges within Company D include people (user) who are not dedicated/interested with the technology and lack of expertise. Strategies adopted are to determine a high demand for a technology, develop processes and networking, and establish a small team dedicated to overcome the challenges that arise during the transfer. Stakeholder analysis/ mapping are used to identify key stakeholders. Trust and openness of the project is promoted among the key people who have the influence to decide whether the outputs from the research become part of the company's processes and or product. The technology must also reach sufficient maturity (e.g. application) in order to build people participation and commitment during the internal technology development. As such, the company established Technology Readiness Levels (TRLs) that assess the maturity of a particular technology. A Potential Exploitation Plan is adopted which requires each project to develop and maintain its own transfer mechanisms (e.g. transfer of people between RC and the company).

The summary of case studies challenges and strategies adopted is shown in Table 3.

Table 3: Summary of Case Studies Challenges and Strategies

Challenges	Strategies
Technical	Low technology maturity requires a system that identifies technology which is more understandable, demonstrable, and unambiguous.
Regulatory (national and organisational level)	Technology compatibility with existing business model requires thorough search and match with company need and demand for certain technology.
	Differences in business culture requires formal technology transfer programmes.
People	Lack of personnel commitment requires formation of technology transfer goal/objective, and establishment of system to provide constant flow of information to the people who are going to use it.
	Lack of resources and support of staff require identification of key stakeholders (e.g. stakeholder analysis/mapping), and appointment/ recruitment of people that have the right attributes based on job specification.
	Lack of acceptance of the new technology requires constant communication and celebrating successful technology transfer.
	Lack of trust urged for complete understanding of the transfer process.

The challenges encountered in each of the previous four cases show that most of the challenges in transferring technology are rooted in people issues followed by regulatory and technical issues. The people challenges include lack of commitment, acceptance, trust, and resources and support. The strategies adopted shows that formal methods are used to overcome most of the technology transfer challenges. The Technology Transfer Package (by Company A) and Standard Operating Procedure (by Company B) provide clear ways of working on what should be done, when, where and by whom. This enables the company to provide good project management and

planning that should leads to smooth technology transfer practices across the whole transfer duration.

CONCLUSIONS AND WAY FORWARD

Technology transfer in manufacturing companies continues to have challenges. This paper highlights these issues and attempts to find strategies by referring to the manufacturing sector's technology transfer practices. Basically, the aim of technology transfer in the manufacturing companies is to increase technological capabilities. This, as a result, creates profit and competitive advantage to the companies in the longer term. The manufacturing companies generally adopted all stages of technology transfer which were assessment, selection, adaptation, development and use of received technologies. In addition, the companies mainly faced "people" challenges in technology transfer followed by regulatory and technical challenges. The key challenges include lack of employees' commitment and motivation towards technology transfer. Similarly, construction also encountered difficulties in attitudes of construction personnel to technology transfer (Carrillo, 1996). The companies' strategies include identifying acceptable matured technologies that match the company's requirement and planning on human resources throughout the technology transfer projects. The assessment of technologies that match the company's requirement may not be suitable for construction since construction companies are searching for a new technology which are project specific. However, construction may adopt the approach to human resources planning as the involvement of employees from the beginning to the end of the project would increase better understanding and promote the transfer among their employees; thus changing their negative perceptions and attitudes towards technology transfer. Other possible lessons that can be learnt include the development of technology transfer goals/objectives and technology transfer programmes. Further work will involve detailed case studies of technology transfer in multi-national construction projects to explore the challenges and strategies used by the construction companies. This would explore the requirement for a detailed framework aimed to facilitate/improve the transfer in construction projects. The developed framework would take lesson learnt from the manufacturing case studies to inform and subsequently improve construction practices in transferring technology.

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