MANUFACTURED CONSTRUCTION: REVISITING THE CONSTRUCTION-MANUFACTURING RELATIONS

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Construction-manufacturing relations became imperative following the Industrial Revolution, and have been hotly debated over the past few decades. Three main schools of theory exist. They are: pro-active learning from manufacturing – construction is backwards; prudent to learning – construction is unique and different from manufacturing; and mutual learning – construction to learn improving quality and efficiency while manufacturing to learn improving effectiveness of dealing with complexity and uncertainty. The past decades have also seen a sweeping agenda of sustainability globally, with the UK government probably having made the most challenging commitments to carbon emissions reductions in general as well as in the built environment. The theory of construction-manufacturing relations is updated, with a focus on examining the business process and production strategies. It is important that construction and manufacturing not be considered as two different philosophies; rather a more interdisciplinary approach should be contemplated for offsite construction projects. A theoretical framework of construction-manufacturing relations is developed, which highlights the importance of a number of influencing factors including industry sectors, context, technology of manufactured construction, business process and activities, and business factors. Thoughts are provided on future research into manipulating the construction-manufacturing relations.

Keywords: manufacturing, offsite production, process.

INTRODUCTION

Over the last 200 years several major changes have taken place, which have imposed a significant impact on manufacturing. The changes started with the advent of the industrial revolution leading to an upsurge in large scale production activities. Beginning of the twentieth century saw Henry Ford propagate the idea of mass production and standardization. His well-known quote, 'You can have any car you want, as long as it is black and model T', clearly indicates his preference of staying away from design customisation. This mass production movement became so strong that manufacturing became almost synonymous with mass production (Crowley, 1998). Customised production could not offer benefits such as economies of scale that mass production offered. Therefore, mass production gained more momentum. The construction sector took ideas from manufacturing and introduced concepts of manufacturing into construction activities. One of the oldest documented manufactured construction buildings, Crystal Palace in London, dates back to 1851 (Gibb, 2001). Gann (1996) traced back the large scale application of manufacturing into construction to 1914 with Le Corbusier's domino house.

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Along with the practical interaction between manufacturing and construction there have been numerous scholarly attempts to disentangle / optimise the relations between them. Such relations have been particularly hotly debated over the past few decades. This may well be explained by the two fundamental drivers for standardisation and preassembly as contended by Gibb (2001:309), namely, 'pragmatism' and 'perception'. Pragmatism denotes 'industry response to an urgent need combined with a lack of resource'. Industry response to an urgent need varies from country to country and from time to time, and examples often quoted are McDonald's Drive-Thru, fuel outlets for Shell, Esso, etc. for leisure and travel in Europe, residential buildings in the UK, Japan and the Netherlands (see Gibb, 2001). Perception stands for 'client and public reaction to a prevailing design philosophy', and Gibb (2001) commented that client and public perception of design has changed to emphasise on achieving value for money, zero defects, minimal waste and environmental impact. The government in the UK has promoted learning from manufacturing in improving quality and efficiency of construction (Egan, 1998). Such promotion, drawing on the buying power of the government as the biggest client in industry as well as its political leverage, has gradually shifted towards addressing the agenda of sustainability in recent years. The sustainability agenda is markedly represented by the government commitments to reducing carbon emissions by 80% below 1990 levels by 2050 and for all new buildings to achieve zero carbon from 2016 (domestic) and from 2019 (non-domestic). Such sustainability agenda introduces opportunities as well as challenges for manufactured construction, which warrants further thinking of implications of sustainability on construction-manufacturing relations.

It is within this context we are inspired to look into the two economic sectors and impacts of the sustainability agenda and to explore how construction-manufacturing relations can be manipulated to help achieve sustainability. The paper reports on our explorative thinking drawing on the first stage of a research proposal in this area. In particular, the theories of construction-manufacturing relations are reviewed, and the implications of sustainability are discussed. A theoretical framework of construction-manufacturing relations is developed, which highlights the importance of a number of influencing factors to business practice as well as future research in the area.

CONSTRUCTION-MANUFACTURING RELATIONS

It is not the purpose of this paper to argue what construction-manufacturing relations and if manufactured construction are beneficial to improve performance of the construction sector. Such proposition is taken from the mainstream of the literature. Instead, the paper reviews and summarises the construction-manufacturing relations, in particularly addressing the challenges and drivers for change. Many exist, but two are focused, namely, sustainability and offsite construction. The past decades have also seen a sweeping agenda of sustainability globally, with the UK government probably having made the most challenging carbon emissions targets in general and in the built environment.

Similarities and differences between construction and manufacturing

It is widely acknowledged that construction is a distinctive economic sector, differing from other ones. Researchers in innovation in construction offer several possible explanations. For example, Nam and Tatum (1988) compared the characteristics of constructed products with those of manufacturing, arguing that five specific differences limit the development of construction technology, namely, immobility, complexity, durability, costliness and high degree of social responsibility. They attributed these characteristics to creating the conditions for production processes that result in the 'locked system' in which changing the status quo becomes difficult. Developing these concepts and linking them to organisational theory, Reichstein *et al.* (2005) identified six factors that shape the nature of innovation in construction as an economic and innovative process. They are liabilities of projects, immobility, uncertain demand, smallness, separation, and assembly. Reichstein *et al.* argued that while each of the liabilities that characterize construction can be identified separately in other manufacturing and service sectors, when combined they provide a contextual environment for innovation that differs from others. Also, Gann (1996) contended that in comparing production techniques it is necessary to note their physical differences, explain organizational aspects of production, and relate these to processes of learning. Buildings, or 'constructed products', differ from other manufactured goods in several respects, which affect the extent to which new production processes can be deployed. For example, in comparison with many products, housing is large and usually immobile; there is a higher degree of complexity in the number and range of component parts; its production on site introduces varying degrees of uniqueness; and housing must be more durable and is often more expensive than other manufactured goods.

Past research into construction-manufacturing relations

Since Henry Ford developed the standard production line for car manufacture, leading European and North American architects, builders and manufacturers have been seduced by the idea of producing houses in factory. Many attempts have been made to transfer knowledge from mass-production of automobiles and other consumer products to low-cost housing production (Gann, 1996). In parallel with the practical interaction between manufacturing and construction there have been many research attempts to address their relations. Developing Winch's (2003a) summary of responses to the criticisms of the performance of the construction industry, we present three main schools of theory of construction-manufacturing relations below.

Pro-active learning from manufacturing – construction is backwards
In this school, commentators advocate radical changes in the way the industry operates. Winch (2003a) commented that attributed to this was the industrialization movement of the 1950s and 1960s (e.g. Gann, 1996), and the lean construction and rethinking construction agenda of the 1990s (e.g. Egan, 1998). Analysts in this school typically use the auto industry as a role model for cross sector analysis.

Prudent to learning – construction is unique and different from manufacturing
Critics in this school argue that construction is not backwards but simply different from the other sectors. The five characteristics of constructed products identified by Nam and Tatum (1988) set a theoretical platform on which many arguments in this school have been developed (e.g. Reichstein *et al.*, 2005). These specificities of construction particularly offer explanations to limitations to innovation and development of construction technology. A more specific, and often cited, example is housebuilding. Ball (1988) argued that the difference between housing production and car manufacturing was mainly due to the role of land in the total purchase price of the constructed product, or the site-specificity of the assembly stages of the construction process. However, when the decoupling between land acquisition and housebuilding process is ensured, as seen in Japan and Germany, learning from auto production is more effectively enabled. Winch (2003a), utilising the industry lifecycle model summarised and developed in Utterback (1994), explored the perception underlying

the first two schools of arguments. He analysed, the industry lifecycle includes “an early fluid phase when product enhancing innovation is the key, and where there is intensive competition between different design concepts, through a transitional phase which witnesses the emergence of a dominant design to a specific phase when competition is between a few large firms through performance improving (particularly cost reducing) innovations” (P. 652). Winch (2003a) then suggested that the perception that construction is ‘stuck’ at the early stage of the life-cycle is arguably the basis for the charge of ‘backwardness’, and further argued that construction is a ‘complex systems industry’ (with characteristics e.g. ‘adamant refusal to move down the product lifecycle, i.e. failure to go through the transformation process), and therefore that general comparisons with industries such as motor vehicles which do move through the product life-cycle are misplaced.

Mutual learning between construction and manufacturing

The logic of mutual learning between construction and manufacturing is perceived to, and should, be embedded in the many attempts to address their relations. Gann (1996) highlighted that the housing industries can benefit by learning more about the use of advanced manufacturing techniques developed in car production, and at the same time, automobile makers may learn more about the management of customization from the way in which housing firms organize sales, design and final assembly. Knowledge particularly about project-based management and engineering in construction can be of value in a wide range of manufacturing firms. Interestingly, Winch (2003b), while acknowledging that project management developed initially in construction, argued that the most important lesson that construction can currently learn from manufacturing is the importance of project management, as it has the oversight of the entire project value system from conception to completion.

Challenges and drivers for change

Manufacturing processes and philosophies initially were thought as panacea for the construction industry and were going to cure all the problems. Egan (1998) recommended manufactured construction as the way forward for improving quality and efficiency of construction. Benefits of mass manufacturing such as economies of scale, better quality and better control and management (Gann, 1996) have been quite attractive for construction industry. Mullens and Arif (2006), drawing on their study of Structural Insulated Panels, demonstrated that significant cost savings and efficiency are achievable with manufactured construction. However, as Crowley (1998:397) said, ‘Solutions from the manufacturing industry cannot be simply applied to the problems of the construction industry, without those solutions being “re-engineered” themselves’. Other scholars such as Polat *et al.* (2006) have also demonstrated that simply moving efforts offsite does not necessarily guarantee efficient production/construction. So the question remains, what construction companies have to be mindful of, when going for manufactured construction? Several authors such as Gann (1996), Crowley (1998) and Gibb (2001) have identified strategic-level issues in manufacturing that could be beneficial to, or serve as obstacle for, offsite construction, but not many have summarized operational-level issues and implications of making manufacturing work for construction.

Current challenges and drivers facing the construction sector could indeed be addressed using offsite production. The biggest challenge is sustainability. Many organisations worldwide have been trying to achieve sustainability in their business processes and operations. Offsite construction has the capability of addressing the environmental dimension of sustainability through reduction of waste (Jaillon and Poon, 2009); economic dimension of sustainability through mass customisation (Nehmens and Mullens, 2009); and social dimension of sustainability by providing better and safer working conditions, greater investment in technology and allied to this is more training of operatives and greater job security (Burgen and Sansom, 2006).

Another challenge is on detailed economic and cash-flow analysis throughout the design-production-construction-maintenance process. Gibb (2001) argued that "Most customers are interested in the end product (the building, or car) but rarely concerned about the processes involved". This is quite true. In fact this is the reason why it is difficult to sell standardized designs to customers. Especially when it comes to housing, this is the biggest investment that most people make in their lifetimes and therefore they want it done in a specific way. However, at the time of offering the product to the customers, detailed cost breakdown information is not available on additional features that customers want in their buildings. If customers are provided a detailed list of cost implications for every personalised design requirement, it might convince them to limit their choices to a smaller number of bespoke features. Neural network and artificial intelligence based forecasting models could help in this respect. Some work has been done by Arif *et al.* (2002) and Nasereddin *et al.* (2007) but more is needed in order to develop detailed costing tools for customers to make informed judgements. The breakup of cost implications for processes and components can potentially help in moving from 'make-to-order' to reducing the design choices and actually moving to 'make-to-forecast' (Winch, 2003b), or maybe moving to what is proposed later in the paper 'make-to-maintain'.

Crowley (1998) presented a list of management philosophies and examined if they are applicable to manufactured construction. One of the areas they have covered is organisation wider information systems. The current Enterprise Resource Planning (ERP) and Electronic Data Interchange based packages do not allow the flexibility of operation needed by manufactured construction organisations given the bespoke nature of the product. Arif *et al.* (2011) proposed a document based, loosely coupled and flexible enterprise-wide information system that has been implemented in a modular home manufacturing plant, but more needs to be done in order to implement this or other similar systems in other manufactured construction organisations. The flow of information and informed decision making could be facilitated if efficient and appropriate IT network exists in the organisation. The use of IT and computers in design, planning and execution of projects can also facilitate more elaborate analysis and identification of problems that can be difficult to deal with at later stages in a construction project. Use of computer aided design and manufacturing can easily be implemented in offsite construction, thus improving the efficiency of the whole construction process (Murray *et al.*, 2003). New technologies such as Building Information Modelling (BIM) can serve as an effective platform for exchanging information between design, manufacturing and any other department involved in a project, and performing impact analysis on decisions in the system.

One question still remains: what exactly is the manufactured construction paradigm? Is it construction adapting good practices from manufacturing or should it be manufacturing invading one more sector to spread the word about its benefits. The discussion so far has followed the former paradigm. If we were to move into the second paradigm, then we would be looking at limiting design choices for customers and going in the direction of mass-customisation. The following section presents a theoretical framework for establishing construction-manufacturing relationship.

THEORETICAL FRAMEWORK OF CONSTRUCTION-MANUFACTURING RELATIONS

Drawing on the critical review of the literature, five sets of factors influencing construction-manufacturing relations are identified (Figure 1). Below we discuss their implications on both future research and practice of manufactured construction, particularly in addressing the overarching sustainability agenda.

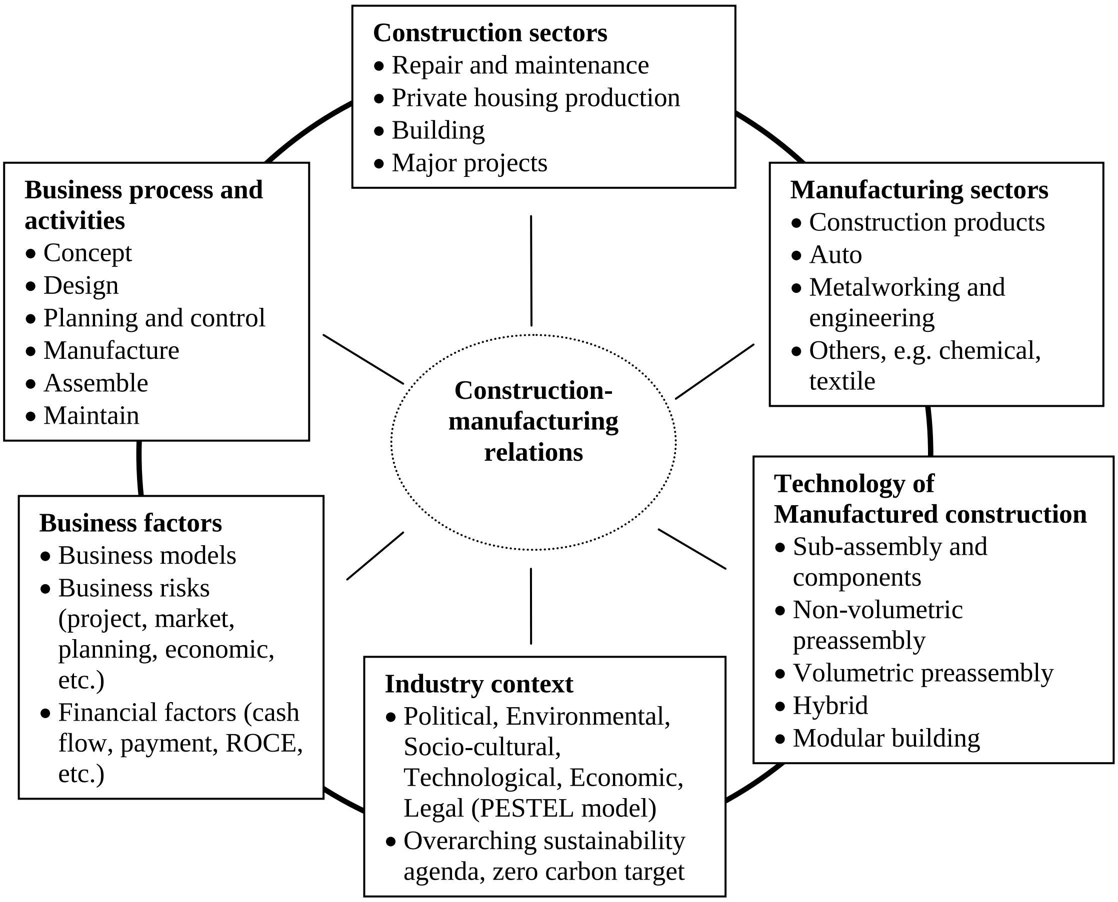

Figure 1: Factors influencing construction-manufacturing relations

Technology of manufactured construction

There are different levels of offsite production technologies, which lead to relevant types of manufactured construction. Goodier and Gibb (2007) presented a typical system of four levels of offsite, from component manufacture and sub-assembly, non-volumetric pre-assembly, volumetric pre-assembly, to whole buildings, with increasing degree of offsite work. It is however important to note that no discrete on-site or offsite solution exists, i.e. even whole building offsite solutions require on-site services connections and preparation of foundation, etc, while conventional site-based labour intensive construction involves building components manufactured offsite, e.g. blocks, lintels. In some sense, construction sites are more like final assembly plants in automobile production. Gann (1996) suggested that the challenge for housing producers is to find innovative ways to improve performance in final on-site assembly stages, perhaps through new forms of project management. Pavitt and Gibb (2003) argued that in cases of offsite production, management of interfaces between building components are more important. Interfacing problems, however, are one of the main factors inhibiting a wider take-up of offsite construction technology (Pan *et al.*, 2008), and are worth further investigation. It is also worth noting wide-ranging innovative materials, technologies and systems boom in the construction industry, either in prototype or mass application, with examples like phase changing material, BIM, low or zero carbon technology and nanotechnology.

Business process and activities

Winch (2003b) explored the relevance of the manufacturing models for the improvement of the performance of the construction process. He argued that "all products produced by discrete assembly industries, including construction, go through a distinctive life-cycle of:

- Concept – the functionality of the product needs to be defined in relation to a particular market demand
- Design – the product needs to be engineered, and detailed – this information is typically captured in an engineering drawing
- Planning and control – the process of manufacture needs to be planned and then controlled against the plan
- Manufacture – the discrete components and subassemblies which make up the final product must be transformed from raw materials into their final form
- Assembly – the discrete components must be assembled to create the finished product".

Winch (2003b) then identified four generic production strategies, namely, concept-to-order, design-to-order, make-to-order, and make-to-forecast. Developing the Winch's model, we have added a stage 'maintain' and its relevant production strategy 'make-to-maintain', and feedback loops to early stages of the process (Figure 2). The make-to-maintain strategy is particularly applied in developments in which clients / developers have long-term interest, e.g. retrofit and social housing production. This strategy sees a huge potential of application, given the fact that 70% of the built environment by 2050 has already been in existence.

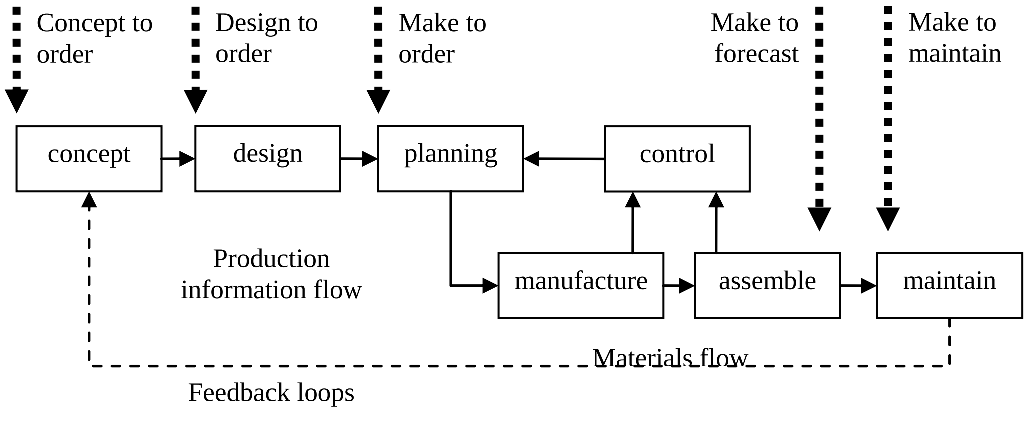

Figure 2: Production process flows. Developed from Winch (2003b:112) Fig 1

Winch (2003a) also utilised the concept of distinctive value systems (Porter, 1985) to challenge the cross-sector comparison. He presented sequentially arranged value chains of A design – B manufacture – C distribute – D maintain, and then pinpointed that the motor vehicles industry, as defined in the Standard Industrial Classifications (SIC), only includes value chains A and B, while C and D are allocated to another sector. In comparison, the SIC for construction excludes A, but includes B, C and D.

In this logic, most product innovation in construction is excluded while repair and maintenance require low levels of innovation and have inherently low productivity due to their labour intensity. He therefore concluded that comparisons of rates and levels of innovation in construction with other industries which do not compare the full value system from A to D for all sectors compared are inherently flawed.

Construction and manufacturing sectors

Many scholars commented on the effectiveness of comparing construction with other manufacturing sectors (e.g. Gann, 1996; Gibb, 2001; Reichstein *et al.*, 2005), while Winch (2003b) addressed this in an analytical way, breaking construction down to sub-industries and matching them to relevant production strategies. He argued that the emphasis should be on manufacturing in the discrete assembly industries most closely analogous to construction, such as the auto industry or broadly known as the engineering or metalworking industry.

Having acknowledged the difference of construction from other manufacturing industries, Winch (2003b:115) analysed the models of organisation in construction sectors (or 'sub-industries'), which is elaborated below:

- Repair and maintenance in construction, which typically accounts for 50% of output, has no comparator in manufacturing (Winch, 2003a), and therefore was not considered.
- Private housing production, which is 'the only sector of construction that sells to final consumers, rather than intermediate clients', is on a 'make-to-forecast' basis when housing production is coupled with land development (e.g. in the UK), and would seem to be on a 'make-to-order' basis when land development gain can be separated from housing production (e.g. in Japan).
- Building, 'meeting the needs of clients for a wide variety of facilities with undemanding technical specifications – traditionally this grouping has included public sector housing provision', which saw a traditional dominance by 'concept-to-order', but moves towards a 'design-to-order' strategy where systems integrators offer modularised solutions, and from the 'design-to-order' to 'make-to-order' strategy for certain standardised building types (e.g. McDonald's restaurants, BP Garages, and hotel chains).
- Major projects, 'which include much infrastructure development, but also highly engineered buildings such as hospitals and high-rise offices', rely largely on 'concept-to-order' strategies.

Industry context and business factors

Industry context is another important factor influencing the evolution of manufactured construction. Relevant analysis should cover the political, environmental, socio-cultural, technological, economic, and legal aspects, rather than any of them per se. particular attention should be paid to the overarching sustainability agenda and low and zero carbon targets which seem to be sweeping globally. In addressing the recovery of UK housebuilding from the recent economic downturn, Ball (2010) warned that the movement towards zero carbon homes to a degree raises a fundamental issue within the housebuilding industry: its relatively slow and, typically, path-specific forms of innovation.

The business process and activities regarding construction-manufacturing relations are outlined above, so are the production strategies in specific sectors of construction. All these, coupled with the industry context, determine the other business factors at the firm level, including business models, business risks and financial factors. Teece (2010) pinpointed that the concept of a business model lacks theoretical grounding in economics or in business studies. Such knowledge seems to be even far under-developed in building and construction disciplines. Pan and Goodier (2011) attempted to address the relations between business models and offsite construction take-up, particularly in the UK housebuilding industry. This area however demands further exploration with empirical evidence.

CONCLUSIONS

Three main schools of theory of construction-manufacturing relations are reviewed. They are: pro-active learning from manufacturing – construction is backwards; prudent to learning – construction is unique and different from manufacturing; and mutual learning – construction to learn improving quality and efficiency while manufacturing to learn improving effectiveness of dealing with complexity and uncertainty. Within a sweeping agenda of sustainability globally, the UK government has made probably the most challenging commitments to carbon reductions in general as well as in the built environment. The theory of construction-manufacturing relations is updated, with a focus on examining the business process and production strategies. It is important that construction and manufacturing not be considered as two different philosophies; rather a more interdisciplinary approach should be contemplated for offsite construction. A theoretical framework of construction-manufacturing relations is developed, which highlights the importance of a number of influencing factors including sectors, industry context, technology of manufactured construction, business process and activities, and business factors. The review warrants future research into such relations, drawing on empirical evidence. Case studies should identify good practice and lessons learnt, and also help illustrate and examine the implications of the factors influencing the construction-manufacturing relations. A focus is worth giving on addressing the challenges from addressing the sustainability agenda and low and zero carbon commitment.

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