How Environments Shape Innovation: The Case of Precast Concrete Crosswall for Multi-Storey Residential Building Construction

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Abstract

Precast concrete crosswall is an innovative offsite production technology, and has played a significant, although debatable, role in the attempts to industrialise construction. Despite well-rehearsed benefits from using crosswall, its uptake in UK multi-storey residential building is currently experiencing a significant slowdown. This calls for research to understand the trajectory of such technology. This paper aims to reveal the influence of external environments surrounding housebuilding organisations on the utilisation of crosswall for multi-storey developments. The research was carried out through a longitudinal case study of using crosswall for constructing 20 multi-storey buildings by a leading UK housebuilder in recent six years. The driving forces and inhibiting factors of external environments in relation to the Political, Economic, Socio-cultural, Technological, Environmental and Legislative (PESTEL) aspects for taking up crosswall during this period were identified. The results suggest that, although it seemed that the housebuilder drove the process of adopting and utilising the innovation, a combination of external forces shaped the development and diffusion of the technology in the company. This complex construct of influences imposed significant impacts on the decision-making process in the company of developing, utilising, reviewing, improving and/or abandoning innovation. Although the company had achieved a technically viable solution with due commercial and efficiency considerations through the six-year learning curve, the use of crosswall was recently suspended, which was primarily attributed to the changes of external environments and consequently in their supply chains. The findings complement the techno-economic and socio-technical theories of innovation, but also expand the spectrum of external environments which shape innovation at organisational level. The paper urges housebuilding organisations to address the dynamics of environments for innovation, but, more importantly, calls for more effective innovation-friendly environments for future residential building.

Keywords: innovation, multi-storey building, offsite production, PESTEL, precast concrete crosswall

1. Introduction

The past one hundred years saw dramatic changes in the use of offsite production methods in UK residential building. Despite the previous research attempts to review the historical account of offsite technologies (e.g. Glass, 2000; Marshall et al., 1998; Ross, 2002; Housing Forum, 2002), few explored the process in which those technologies were developed, adopted, diffused, reviewed, and dropped or re-developed at organisational level. Although some research provided strategies for managing offsite (e.g. Pan et al., 2008), there is little information on the interrelationship between organisational strategies for utilising offsite and challenges arising from changes to macro environments of innovation. Similar to the 'back and forth' in the history in relation to the take-up of offsite, such technology is again facing challenges from the current housing market downturn resulted from the global economic recession (Building, 2008). Precast concrete crosswall is an innovative offsite production technology, which employs factory precast, precision engineered, concrete components, each of which is custom designed and manufactured offsite to suit the specific project (The Concrete Centre, 2007). Crosswall systems incorporate internal walls normally suitable for direct decoration and external walls as either perimeter wall infill or integrating cladding to satisfy functional and aesthetic requirements (Glass, 2000). Crosswall technology has played a significant, although debatable, role in the attempts to industrialise construction. Despite well-rehearsed benefits from using crosswall, its uptake in multi-storey residential building construction in the UK is currently experiencing another significant slowdown. This calls for research to understand the trajectory of such technology and review its uptake in residential building in turbulent environments surrounding housebuilding organisations.

This paper aims to reveal the influence of external environments on the utilisation of crosswall for multi-storey developments at organisational level. This research follows on a previous study which revealed an insight into the utilisation of crosswall for multi-storey residential buildings in the organisational context (Pan et al., 2009). The paper investigates the factors which inhibited and enabled the adoption and development of crosswall technology in a series of multi-storey crosswall projects. It identifies the roles played by project stakeholders in the process, and then examines the organisational strategies for managing crosswall technology in response to changes to external environments. The study was focused on multi-storey residential buildings rather than low-rise housing. For multi-storey residential buildings this paper adopts the definition of multi-family buildings with more than four storeys (Guertler and Smith, 2006). The focus on multi-storey buildings appears under-researched but important as that some 36million European households are in high-rise residences, equivalent to one in six of all households in Europe (ibid.). Also, high-rise development had attracted a strong attention in the UK in the past decade (Knight Frank, 2009).

2. A brief historical review of UK crosswall construction

The end of the First World War saw an urgent huge need for housing in the UK. With the then government's encouragement, large numbers of different construction systems were approved (Marshall et al., 1998; Ross, 2002). However, precast concrete housing construction did not gain its popularity until the mid 20th century. Precast concrete and other forms of industrialised construction were used to address the problems of the loss of some 200,000 houses due to bombing and damage to about 25% of the entire building stock during the Second World War, shortages of building materials and labour, and an increasing population at the time (Marshall et al., 1998). As a result, more than 250 precast concrete 'systems' have been acknowledged, but less than 100 were deemed to be sufficiently robust or durable to warrant further commercial development (Glass, 2000).

In the early 1960's, another further, sudden increase in demand meant that precast concrete systems were used yet again as a replacement for other unfeasibly labour-intensive conventional construction methods. By 1960, over 165,000 precast concrete dwellings had been built, ranging from small single storey bungalows to large high-rise blocks (Glass, 2000). Also, other concrete systems were 'imported' to the UK mainly for the construction of high-rise buildings, of which the large panel system suffered a major setback in the Ronan Point collapse in 1968 caused by a gas explosion in a block of flats in East London. Ronan Point's construction was a result of over-speedy execution of the precise concrete panel system where a lack of structural continuity at the joints of precast components, leading to progressive collapse, was to blame. A housing industry in desperate need of dwellings could be vulnerable to such shortcuts. In the public's perception, precast concrete in housing has become unfortunately associated with 1960's 'social engineering', resulting in ill-matched housing types and social groupings, and 'social malaise' of high-rise dwellings, although it had been proven that actual structural failures were due principally to poor understanding of materials technology, poor workmanship and a lack of quality control on site (Glass, 2000). The 1970's saw a reaction against system building in general. This was basically as a result of the problems of maintenance and repair caused by poor design, inadequately controlled prefabrication processes, and/or poor construction due to the use of unskilled labour and/or poor site management (Marshall et al., 1998). In the early 1980's, the then Conservative government had introduced 'Right to Buy' legislation which led to the purchase of a great number of system-built local authority houses. Those houses constructed with pre-cast components were often affected by carbonation or chloride attack, many of which were refused by building societies for mortgage or re-mortgage (Ross, 2002). After mid 1980's, significant developments took place in component-based systems, but there was very little in the way of complete housing systems development (Housing Forum, 2002).

In 1998, the publication of the Egan Report called for radical improvement in quality and efficiency of housing construction. This desire, coupled with the pressure from increasing housing demand, formed the backdrop for the growing interest in offsite. In a similar manner to previous historical efforts, the housebuilding industry has again come under pressure to adopt offsite and modern methods of construction (MMC) (ODPM, 2003). The invention of the term MMC intended to reflect technical improvements in prefabrication. However, a recent survey identifies that the extent of crosswall application in the UK domestic sector was low (Pan et al., 2008). With effects on the housebuilding industry from the recent economy recession, there had been criticisms on the over-provision of small flats in high-rise residential developments (Knight Frank, 2009). Associated with the significant slowdown of high-rise developments was the dramatic reduction of the use of crosswall for residential building. Most housebuilding organisations were forced to review their use of construction methods and examine their technology strategies in order to survive the economic recession.

3. Methodology

The research was carried out through a longitudinal case study of the use of crosswall technology in the context of eight projects of a leading UK housebuilding organisation. These projects, labelled A to H (Table 1), altogether, included 20 multi-storey buildings, providing 1930 units of apartments. The superstructure of all the buildings was designed in crosswall methods. These buildings ranged from the first crosswall multi-storey constructed by the housebuilder in 2004 to the current high-rise up to 20 storeys utilising crosswall sandwich panels, which represents the six-year innovation journey of the company of exploring the use of crosswall technology. The longitudinal research design was grounded on theories regarding innovation as a complex and challenging multi-factor process (Jones and Saad, 2003), for which the period of six years and the cross-project nature of the investigation enabled a valid and reliable in-depth case study of the innovative technology.

Approaches to studying technology innovation abound in the literature, and they originated from the simple linear ‘market-pull’ and ‘technology-push’ (Schumpeter, 1934) theories and evolved to more complex, integrated innovation models like ‘socio-technical’ (Trist, 1981) and ‘techno-economic’ (Freeman and Perez, 1988) approaches, and ‘systems integration and networking’ model (Rothwell, 1992). However, the linear theories ignore the complex interrelations between the different aspects of the system in which innovation is developed and diffused. The more complex, integrated models, by focusing on some of the aspects of the systems of innovation, overlook the other important ones. In this study, the strategic management tool of PESTEL framework (see Johnson and Scholes, 2002) was used for the analysis of the environmental context including political, economic, socio-cultural, technological, environmental and legislative aspects. The external inhibiting and enabling factors to utilising crosswall technology were examined.

This organisational case study involved document analysis and personal interviews and workshops with the personnel of the housebuilder from both senior management and project operational levels which covered the roles including design, technical, construction, estimating, buying, innovation and sustainability. Representatives of the supply chains of the housebuilder were also interviewed to validate data on the utilisation of crosswall methods. Case study data consisted of interview notes, observations, documentary data, impressions and statements of participants, and contextual information. Given the diverse sources of information and the nature of accumulating data through the projects and buildings, the process of constructing case study data suggested by Patton (2002) was used for analysis, which included assembling the raw case data, constructing a case record and writing a final case study narrative presented chronologically and thematically. Three concurrent flows of activity: data reduction, data display and conclusion drawing and verification by follow-up discussions with key participants were used for making sense of the data. These analytic procedures and strategies enabled the meaningful presentation of the results of the study and the development of relevant arguments.

Table 1: Details of the projects studied

Project	*Year of construction*	*Number of storeys*	*Number of buildings*	*Number of dwellings*	*Building detail*	*Procurement*	*Construction method*
A	*2004*	*9/7*	*2 (a/b)*	*47/55*	*Full external scaffold, no basement*	*Contractor 1; newly formed project team*	*Precast concrete crosswall system: crosswall panels and precast concrete floor planks topped with 75mm screeding*
B	*2005*	*5*	*1*	*80*	*Full external scaffold, no basement*	*Contractor 1*	*Same precast concrete crosswall system as in Project A*
C	*2006*	*13/8/5*	*3(a/b/c)*	*72/57/42*	*Mast climbers (no external scaffold), on and off-grid undercroft car park*	*Contractor 2; extended supply chains; developed effective project team*	*Similar precast concrete crosswall system to in Project A, and insitu concrete for off-grid undercroft car park*
D	*2007*	*10/9*	*2(a/b)*	*68/47*	*No basement, curved façade*	*Contractor 3; built supply chain database; R&D benchmarking*	*Similar precast concrete crosswall system to in Project A, and offsite produced curved façade*
E	*2007*	*7/5/4*	*3(a/b/c)*	*119/77/64*	*On and off-grid undercroft*	*Contractor 2;*	*Similar precast concrete crosswall system, but 125mm wall system developed from usual 150mm; tailored undercroft design to avoid insitu concrete work*
F	*2008*	*9*	*1*	*152*	*3 storey podium*	*Contractor 2; kind of partnering agreement*	*Similar precast concrete crosswall system for upper floors; insitu concrete work for podium*
G	*2009 (suspended)*	*16*	*5*	*630*	*Crosswall with sandwich panels, with podium*	*Contractor 2; multinational supply chains*	*Similar precast concrete crosswall system, but with sandwich external wall panels, eliminating on-site cladding & external scaffold*
H	*2009 (suspended)*	*20*	*3*	*420*	*Crosswall with sandwich panels, with podium*	*Contractor 2; multinational supply chains*	*Similar precast concrete crosswall system, but with sandwich external wall panels, eliminating on-site cladding & external scaffold; additional engineering work to ensure structural stability*

4. Results and analysis

4.1 Factors enabling & inhibiting crosswall take-up

The six-year period studied saw dramatic changes to the macro environments surrounding the housebuilder. These changes were interwoven and complex, but could be structured, for clarity, in the categories of political, economic, socio-cultural, technological, environmental and legislative aspects. The enabling forces were considered to include: government housing and planning policies in delivering sustainable communities and urban regeneration; government promotion of offsite and MMC; economic development leading to a stronger purchase market; rise of 'buy-to-let' market; preference of urban lifestyle of special social groups like younger generation and 'key workers'; precast concrete technology development from their historical versions; a good number of suppliers and specialist contractors available in the market; increasing public concerns on environmental issues; and increasingly stringent building regulations and voluntary higher environmental standards. These changes, together, shaped the adoption and utilisation of crosswall technology in the company. The interviewees claimed that the primary driver for the housebuilder to utilise crosswall was its simplicity which enabled the company to construct buildings up to 20 storeys using 'in-house build' management, i.e. without the need to engage a specialist main contractor. This was seen as a major gain from both procurement and contractual aspects. The major inhibiting factor was considered to be the lack of housing sales as a result of the market downturn and a rapidly decreased preference of purchasers for flats in multi-storey buildings.

4.2 Roles of project stakeholders in the 6-year innovation process

A range of project stakeholders were identified in the six-year process of taking up crosswall technology, which included the housebuilder, the specialist concrete contractor and their supply chain, Health & Safety Executive (HSE), building controls, planning authorities, institutions, customers and the public. The housebuilder aspired to explore a technological solution to constructing multi-storey buildings without engaging a specialist main contractor. The housebuilder drove and led the process of adopting and developing crosswall technology in the innovation journey. They took the roles of the main contractor and project management, which covered the responsibilities of outline designs, detailed design coordination, procurement and construction. The specialist concrete contractor undertook detailed designs, supplied the crosswall system and provided installation services. The specialist concrete contractor and their suppliers were proactively involved in the whole process, and they were keen to expand their crosswall market share in the UK domestic sector. Other project stakeholders, e.g. HSE, building controls and planning authorities, were not involved in the decisions of adopting and developing the crosswall technology. However, their positive feedback on reduced health & safety risk and improved build quality by utilising crosswall systems encouraged the diffusion and further development of the technology across the company. The institutions, e.g. The

Concrete Centre, British Precast Concrete Federation, Structural Precast Association, were involved in early consultations of utilising crosswall. The useful information on this type of construction provided by the institutions contributed to knowledge accumulation in the company. The institutions also helped diffuse learning from the projects by publishing industry case studies. The customers, i.e. the investors, individual dwelling purchasers, and the public, were not involved in the decisions of utilising crosswall. However, the general promising UK housing market during the period from the late 1990's to 2007/2008 encouraged the urban development of multi-storey buildings (Knight Frank, 2009). This provided a good opportunity, at the time, for the market expansion of crosswall technology which is associated with fast construction (The Concrete Centre, 2007).

4.3 The housebuilder's responses to environment changes

Against the changes to the macro environments, the housebuilder responded in the aspects of technological development, procurement management, design and cost re-engineering, and organisational learning. These responses had evolved over the time and the projects.

The responses in the aspects of technological development, procurement management, design and cost re-engineering were concurrent and reflected in the whole process of innovation. Within the context of the then promising housing market and positive policies favouring urban regeneration and high-rise developments marked by the publication of the government's Sustainable Communities Plan (ODPM, 2003), the housebuilder adopted the initial crosswall method for Project A & B, and adapted it to the business context and project specifics. The approach was then modified for Project C through F. The modifications to the initial method included: a) replacing full external scaffold by mast climbers, b) developing 125mm crosswall panels from usual 150mm, c) re-engineering design to enable on- or off-grid crosswall undercroft/podium structures to avoid insitu concrete work, and d) modifying design, engineering and contractual solutions to suit partnering arrangements. These modifications sustained the use of crosswall in the subsequent projects by not only improving the technical and management performance but also providing the 'cost engineering' means. Through Project A to F, the housebuilder had developed and proved a technically feasible and cost-effective solution to constructing multi-storey residential buildings using 'in-house' management. The innovation journey demonstrated an effective learning process of the housebuilding organisation in terms of managing and implementing crosswall technology. A learning culture was evident in the organisation and reflected in their routine management processes and procedures. Following the process, a 'novel', more appropriate system, crosswall sandwich panels, was re-invented for Project G & H in order to secure better value by integrating cladding into external wall panels in factory and therefore eliminating the use of external scaffold on site. However, these two projects were recently suspended due to the negative economic climate and a consequent significant drop of housing unit sales of the company. The discussion with senior managers of the housebuilder suggests that the company was seeking alternative development solutions for these two projects. The company expressed no aspiration to build any further multi-storey schemes until market conditions improve.

5. Discussion

5.1 The market and innovative construction technology take-up

The process of innovation, although apparently led and driven by the housebuilder, was predominantly enabled by the promising housing market from 2003 to 2007/08 but inhibited by the market downturn from 2007/08 to 2009. The suspension of Project G & H was based on considerations for the market rather than the use of any specific construction method. These results do not support the simple linear ‘market-pull’ or ‘technology-push’ innovation theories (Schumpeter, 1934). They also question the more complex, integrated innovation theories, although they show the involvement of a range of project stakeholders in the process of innovation and a complex construct of influences from these parties. The results indicate that the market conditions played the most significant role for enabling as well as inhibiting innovation. When the ‘market-pull’ emerged, it was the housebuilder who drove and led the innovation process. However, it was also the market, when the pull function disappeared, that ‘killed’ the innovation, no matter how successful it was. Clearly, this finding is not in agreement with that of many other innovation studies in context other than UK housebuilding, which are more associated with claims for technology-driven innovation. The attributes of UK housebuilding suggest that the industry is commercial driven, with a strong focus on land acquisition. Also, despite significant promotion of offsite and MMC (Egan, 1998; ODPM, 2003), UK residential building is still dominated by conventional methods. Few housebuilding organisations appear to position technological innovation as their corporate strategy. In the current housing market conditions, there are increasing criticisms on the over-provision of small flats in urban high-rise developments. Without supportive government policy, the future of high-rise residential developments is questionable, so is that of their associated technologies, e.g. crosswall. A far more conservative approach to development, concentrating on family homes in suburban and fringe-rural settings, is likely to emerge from the current crisis, and most companies will avoid high-density apartment schemes in more urban locations (Knight Frank, 2009). As suggested by Gann et al. (1998), a characteristic of the UK new-home market is that purchasers and users who, as a whole, are a fragmented and passive group with a strong preference for a traditionally-looking house. If the future of UK new-build homes mainly lies in traditionally-looking family homes, the future of industrialisation of UK housebuilding will then probably face significant market and socio-cultural resistance.

5.2 Champion and leadership to sustain innovation

The housebuilder took the leadership in the process of adopting and utilising crosswall. Such leadership was claimed by Jones and Saad (2003) to be required to bring about substantial internal and external structural and attitudinal changes needed. However, such leadership was effective only when the ‘market-pull’ existed. When the ‘market-pull’ vanished, the housebuilder’s leadership became ‘rootless’ and eventually disappeared. The housing products and their associated building technology went back to more conventional options. This result suggests that the leading or championing force needs to be stimulated and nurtured in order to sustain innovation. The study of the process taken by the housebuilder for adopting, developing and subsequently suspending the use of crosswall provides empirical evidence which supports the suggestion of Tushman and Moore (1988) that innovation should be linked to an organisation's strategy and driven by an assessment of external opportunities and threats. Managing innovation involves mediation between external forces for change and internal forces for stability. This also echoes the suggestion by Gann et al. (1998) that construction firms must function effectively in their role as intermediaries if technologies originating upstream in the supply chain are to be integrated and used successfully within buildings. Therefore, this paper questions the conventional criticisms of housebuilders for their reluctance and inability to innovate (see e.g. Ball, 1999). Instead, the results suggest that the macro environments, part of the systems of innovation, shaped the up-take of crosswall of the housebuilder.

5.3 Regulations and technology innovation

Regulations are part of the institutional setting, within which technological innovation flourishes, vanishes, or remains inert. However, the results of this study suggest that regulations, although important to the company's technology use, did not directly affect the innovation journey of utilising crosswall. Regulations normally do not specify construction methods to use but provide performance standards to achieve. Therefore, in the housebuilding sector, this performance-based regulatory framework leaves freedom to developers and housebuilders and their professional advisers to decide the use of construction methods. This freedom typically leads to a commercially dominant technology decision-making of individual organisations at corporate or project level. As a result, an industry-wide take-up of any specific innovative construction technology is difficult to take place. Gann et al. (1998) argued that detailed sector-specific knowledge is required to develop an appropriate regulatory framework for buildings, particularly if accommodation and stimulation of technological innovation is one of the desired outcomes. The sector-specific knowledge covers types of market, technologies, firm-level competencies, structure of industry and competition, and technical infrastructure. Such knowledge is naturally perceived to be obtained by the regulatory bodies, i.e. the government and its agencies, which is important if technological innovation in high-rise building is to be stimulated. However, whether or not high-rise residential buildings should be supported is another issue.

5.4 Innovation systems and technology take-up

The use of crosswall systems can result in a fast, simple construction process on site followed quickly by finishing trades, which should contribute to industrialisation of UK housebuilding. This advantage has been of great interest to hoteliers, student accommodation developers and other similar clients with high demands on time and quality, whilst it was much less appealing to housing which was generally less repetitive (Glass, 2000). However, opportunities arose for precast concrete construction from the start of the 21st century marked by a revival of high-rise developments in the UK. Nelson and Nelson (2002) believed that further development of the innovation systems idea would be significantly facilitated if more formal economic evolutionary theory were able to take abroad institutional analysis. This belief is supported in this study in which the trajectory of innovative crosswall technology reflected the prominence of reviewing and responding to changes to macro environments for housebuilding organisations. The innovation journey of the housebuilder of utilising crosswall provides evidence to elucidate the two-way interaction between the evolutionary and institutional economic theories, with physical and social technologies respectively (see Nelson and Nelson, 2002). Furthermore, the six-year journey of adopting, adapting, modifying and re-inventing crosswall technology suggests different roles and effects of evolutionary and institutional economic theories in technological innovation. Within the encouraging institutional context, the primary driving force to innovate was the company who led the process of implementing crosswall methods. The continuous engagement with the technology provided the company with a possibility to build up to 20 storeys without engaging a specialist main contractor. This technology breakthrough led to the management breakthrough and consequently significant cost savings and efficiency improvement. At the end of the six-year journey, despite a technologically viable solution for high-rise developments and matured project management expertise, the utilisation of crosswall was suspended. Therefore, albeit an overall consistence with the innovation systems idea, the results of this study suggest that institutional structures have a determinant effect on technological innovation, rather than that technologies shape institutional structures, in the current UK housing sector. However, when an encouraging institutional context existed, the driving force of technological development by the housebuilder was a must for furthering innovation. Nelson and Nelson (2002) posited that physical and social technologies co-evolve and that this co-evolutionary process drives economic growth. The findings of this study, however, suggest an unbalanced interdependence between these two schools of theories reflected in the current UK housebuilding practice.

It would not be surprising to see that many housebuilders will set back to the use of more conventional construction methods. It appears that this cultural setback, coupled with the significant skills loss in UK housebuilding (Knight Frank, 2009), will lead to a longer time and a more difficult process for the industry to take up innovation when the ‘market-pull’ revives in the future. This potential risk is significant given the under-supply of housing marked by the government’s pledge to deliver three million new homes by 2020 (Stewart, 2007).

6. Conclusions

This paper has revealed the influence of external environments on the utilisation of crosswall for multi-storey residential developments in the UK. A combination of political, economic, socio-cultural, technological, environmental and legislative forces shaped the adoption and diffusion of crosswall technology in UK housebuilding. This complex construct of influences imposed significant impacts on the decision-making process in the housebuilder of developing, adopting, adapting, modifying and/or abandoning crosswall technology. Although the company had achieved a technically viable solution with due commercial and efficiency considerations through the six-year learning curve, the use of crosswall was recently suspended. The housebuilder proactively drove the process of innovation. However, it was believed to be the significant slowdown of high-rise developments that ‘killed’ the innovation. This phenomenon was primarily attributed to the changes to external environments and consequently in their supply chains. Despite generally-recognised theories of innovation regarding it as systems, the results from this study suggest a dominant influence of macro environments on technology innovation. The intention of the housebuilder to, or not to, implement innovation was fairly dependent on changes to macro environments. The findings complement the techno-economic and socio-technical theories of innovation development, but also expand the spectrum of external environments which shape innovation at organisational level. Housebuilding organisations are urged to address the dynamics of macro environments for innovation in order to mitigate external risks. Knowledge accumulated through innovation journey should be maintained to gain market competitiveness for any revival of crosswall in the future. More importantly, more effective innovation-friendly environments are required. The housing and planning policy environments should enable ‘market-pull’ for innovation and embrace the leading and championing force in order to sustain innovation in future residential building.

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