Analysis of Construction Innovation Process at Project Level

Beliz Ozorhon[1]

Abstract: In the construction sector, innovation is cocreated in a multiparty environment and shaped by the requirements of the project. Therefore, the analysis of innovation at the project level is essential. This research investigates the innovation process in construction projects. It proposes a framework to explore various components of innovation, including the drivers, inputs, enablers, barriers, innovative activities, benefits, and impacts. The framework is employed in four case studies concerning award winning projects in the UK. The primary source of product, process, and organizational innovations in these cases has been agendas driven by environmental sustainability. Collaborative working among team members and strong commitment proved to be the primary enablers of innovation; reluctance, inexperience, and cost were regarded as barriers to innovation. This study helps to develop a better understanding of the interorganizational nature of construction innovations, thereby improving innovation performance. The developed framework is expected to be applicable to other project-based environments. **DOI: 10.1061/(ASCE)ME.1943-5479.0000157.** © *2013 American Society of Civil Engineers.*

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Introduction

Innovation has long been recognized as one of the key factors contributing to national economic growth, competitiveness, and higher living standards, and has recently been at the heart of the knowledge-based economy [Organization for Economic Cooperation and Development (OECD) 2005; European Commission (EC) 2010]. Whether technical or not, innovation is complex, nonlinear and dynamic; there is a lack of a clear definition or well established classification of innovation. In the UK, the Department of Trade and Industry (DTI) states that innovation is "the successful exploitation of new ideas" (DTI 2007). Innovation can also be defined as "the adoption of an idea or behavior, whether a system, policy, program, device, process, product or service, that is new to the adopting organization" (Damanpour 1992). OECD (2005) distinguishes between technological and nontechnological (including organizational and marketing) innovation. It defines innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD 2005).

Innovation has a context sensitive nature; for instance, patterns of innovation in manufacturing differ from those in services (DTI 2007). Therefore, the analysis of innovation in a specific sector should take into account the characteristics of that sector. Construction is a diverse and project-based industry. It is partly manufacturing (materials, components, and equipment) and partly services (engineering, design, surveying, consulting, and management) (Blayse and Manley 2004). Unlike other industries, construction involves the production of unique projects on site by a variety of teams that are temporarily brought together. Much of construction innovation is codeveloped at the project level. However, most of the literature has focused on investigating innovation at the firm level, and the project level has largely been ignored. This is primarily because of the difficulties in monitoring the different activities conducted by different parties in each stage of a construction project (Dulaimi et al. 2002; Blayse and Manley 2004).

The primary objective of this study is to investigate the ways in which innovation occurs in construction project settings. In this respect, a framework is developed to analyze the determinants and outcomes of construction innovation process, taking into account the characteristics of the project environment. The framework is employed in four case studies of construction projects in the northwest of England. Many technical and nontechnical innovations were analyzed, including modern methods of construction (MMC), energy efficient technologies, lean construction, and community engagement. Findings are expected to guide future research investigating project-based innovation.

Innovation Process in Construction

Much literature has focused on how construction companies manage the innovation process at the firm level. For example, Tatum (1987) described the technological innovation process within individual construction firms. This study identified the following major elements of innovation as recognizing forces and opportunities for innovation; creating a climate for innovation; developing the necessary capabilities; providing new construction technologies; experimenting and refining; and implementing. Slaughter (2000) presented a detailed framework in which the six stages of innovation implementation activity are defined as identification, evaluation, commitment, preparation, use, and post-use evaluation. Dikmen et al. (2005) defined construction innovation as a system in which the elements of the model are objectives, strategies, environmental barriers/drivers, and organizational factors. These studies discuss innovation management from the point of view of an individual firm.

[1]Assistant Professor, Dept. of Civil Engineering, Bogazici Univ., 34342 Istanbul, Turkey. E-mail: beliz.ozorhon@boun.edu.tr

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Mention (2011) stated that innovation is "an interactive process between the firm and its environment, as the result of the collaboration between a wide variety of actors, located both inside and outside the firm." Project-based firms need to manage innovation across organizational boundaries, within networks of interdependent suppliers, customers, and regulatory bodies (Gann and Salter 2000). This has been further investigated by Dewick and Miozzo (2004), who discussed the effect of positive interorganizational relations in the diffusion of sustainable technologies in the Scottish housing market. Similarly, Holmen et al. (2005) emphasized the significance of building relationships for technological innovations and Rutten et al. (2009) presented a literature synthesis on the role of cooperation as an enabler of construction innovation. Although these studies emphasize the need for strong interorganizational relations to enable innovation, they do not analyze the project-specific conditions fostering innovation.

Construction firms often innovate at the project level because their work is always unique, always delivered to bespoke designs, and always achieves something new (Keegan and Turner 2002). Much of the innovation is codeveloped with other project participants, such as clients, contractors, subcontractors, suppliers, consultants, and designers, all of whom has a different role in the innovation process. For example, clients can act as a catalyst to foster innovation by exerting pressure on project participants to improve performance (Gann and Salter 2000), demanding high standards of work (Barlow 2000), or having novel requirements (Seaden and Manseau 2001). Contractors, on the other hand, act as mediators implementing process and organizational innovations [National Endowment for Science, Technology and the Arts (NESTA) 2007], whereas manufacturing firms develop product and process innovations (Gann 1997).

In the *Rethinking Construction* report, Egan (1998) identifies integrated design and build arrangements, including partnering and supply chain management, as key drivers for excellence and innovation in construction. Similarly, Robichaud and Anantatmula (2011) mention the need for several modifications in traditional project management practices to deliver innovative and green construction. They suggest that integration should be achieved through the early involvement of all stakeholders to ensure that the objectives of the project are understood and met in every phase of the project life cycle.

Considering the multiparty environment in construction, innovation analysis should be done at the project level and should take into account the role of project stakeholders and their interrelationships. This approach will help to identify the conditions under which innovation can flourish in a construction project setting.

Research Methodology

In this research, a qualitative case study methodology has been employed to gain a better understanding of the project-based practices and corporate policies in achieving innovation. The objective has been to find answers to the following: why the innovation process is initiated; how the innovation process is enabled; and what can be achieved through the innovation process. In this respect, four construction projects that adopted technical (product/process) and nontechnical (organizational) innovations were examined as cases. The views of different stakeholders, including clients, contractors, and consultants, were sought. The case studies provided lessons on how to successfully implement innovation in construction project settings.

The case study projects were identified in collaboration with the Centre for Construction Innovation Northwest (CCI). CCI is the regional partner of Constructing Excellence (CE), which aims at enhancing the performance of the UK construction industry. It organizes the North West Regional Construction Awards every year to reward projects that demonstrate best practices, with particular emphasis on innovation. The 2009 award winners were identified as potential case study projects. Out of the 17 winners, four projects that introduced different types of innovations were selected.

The first project concerned the development of an eco-supermarket and received the award for best practice in its subregion. The second project concerned the development of the eco-residences of a university and received the award for environmental sustainability. The third project concerned the development of an estate regeneration scheme and received the award for best practice in its subregion. Finally, the fourth project concerned a coastal defense scheme and received the award for best project of the year. The innovation experiences in those projects were explored through a series of half-day interviews, with many participants from the client, contractor, and design organizations. Relevant project information and the interviewees are shown in Table 1.

Fig. 1 depicts the proposed innovation framework. It defines innovation as a system that has several components relating to the participating organizations and to project-specific factors. The components of the innovation process lie on one side and the project participants on the other within a three-dimensional project environment. The primary components of the innovation system are the drivers, inputs, enablers, barriers, innovative activities, benefits, and impacts. The drivers represent the primary motivations for the innovation process to initiate. The inputs are the resources utilized to develop or adopt different types of innovations (product, process, or organizational). The barriers act as the obstacles or challenges working against the innovation. The enablers are those factors overcoming the barriers and increasing the rate of innovations. Benefits are considered to be the project-level outputs, whereas impacts are considered to be wider outputs on the participants of the project. Each participant contributes to and benefits from the innovations introduced. The process is cyclic because the experience and knowledge gained by the project parties may be transferred to future projects in implementing similar or different innovations.

Table 1. Components of the Innovation Framework Discussed during the Interviews

Case	Type, size, and duration	Interview participants
I	Eco-friendly supermarket, UK£20 million, 15 months	Property services director from the client, a civil engineer from the contractor, and the manager of the technology center from the consultant
II	Eco-residences in a university campus, UK£23.9 million, 33 months	Director of the estates from the client, the product development manager from the residential developer, a civil engineer from the contractor, and the head of the design team from the architect
III	Estate regeneration project, UK£29 million, 36 months	Performance and quality manager from the client, project manager from the contractor, and business development manager from the contractor
IV	Sea defense and promenade scheme, UK£21 million, 30 months	Head of engineering services from the client, project manager from the contractor, and business development director from the contractor

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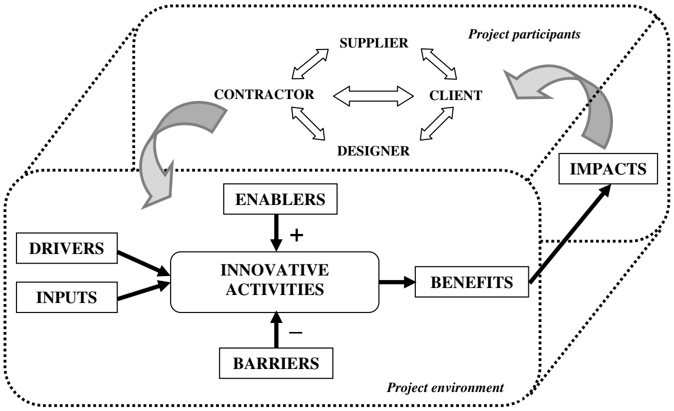

Fig. 1. Framework to explain the innovation process in a construction project setting

The proposed framework was used in the case studies to analyze the construction innovation process. Semistructured interviews were conducted with the case study participants to examine the collaborative ways in which successful innovations were generated. Table 2 lists the issues addressed during the interviews, based on the components of the innovation framework.

In addition to the interviews, other sources of evidence were examined. CCI provided the application forms for the awards, describing the details of each project and adopted innovations. Corporate documents were also shared by the interviewees, including environmental policies, waste management plans, innovation policies, business plans, reports on key performance indicators, and images and videos. The documents were examined before, during, and following the interviews. The transcribed recorded interviews, company documents, and the application forms for the awards were used to analyze the innovation process for each case. Multiple sources of evidence were used to minimize bias in data collection.

Analysis of the Innovation Process through the Case Studies

The four case studies described in the following examine the innovation experiences of each project, placing emphasis on the determinants and outcomes of construction innovation. In each case, relevant project information is presented, factors leading to innovation success are examined, and the outcomes (benefits and impacts) derived through the innovative activities are highlighted. Following the cases, a table is presented that depicts the components of the different types of innovations achieved.

Case 1: Environmental Format Store

The environmental format store scheme was the first repeatable format to be built for one of the major food retailers in the UK, with the aim of becoming the standard design format for future stores. A mixture of new construction techniques was employed to deliver an environmentally friendly, energy efficient, sustainable, innovative, integrated, and value added project, while achieving client satisfaction.

The project is notable for its use of a client-driven approach to innovation at the idea generation stage. The client recognized the importance of delivering high environmental performance and set an agenda to reduce carbon emission by at least 50% by 2020 throughout their operations. The Code for Sustainable Homes (CfSH), which is an initiative of the UK government to create sustainable homes [Department for Communities and Local Government (DCLG) 2006], has been used as benchmark in this respect.

The contractor of the project has been partnered with the client since 1985, when the client decided to form strategic alliances with their contractors. The key reason for these alliances was to keep innovating their supermarket buildings so that they would be built faster for less money and would deliver high performance.

The amount of research and development (R&D) work undertaken in the project has been substantial. The client has its own R&D department and a small non-trade concept store open to the contractor in which to test their ideas. In addition, the technology center within the contractor's organization worked as an internal consultant and played a major role in saving time and money by using the contractor's own resources.

Many innovations that helped to reduce energy usage were introduced. These include a hybrid timber frame, a sustainable cladding system, a recycled and prefabricated walling system, a premanufactured polycarbonate roof light system, a combined heat and power unit, CO_2 refrigeration, and CO_2 sensors.

The innovation process was not free of challenges. First, each project member had their own concerns, contributions, and expectations, with the architect focusing on aesthetics, the cost consultant on decreasing costs, the engineers on structural performance, and the contractor on customer satisfaction. Second, products that

Table 2. Components of the Innovation Framework Discussed during the Interviews

Components	Description and relevant indicators
Project environment	Type and size of the project; parties involved; primary objectives and achievements of the project
Drivers	Primary reasons and sources of motivation to innovate such as end user requirements; competition level; project and corporate performance improvement; technological developments; regulations; environmental sustainability
Inputs	Resources utilized to innovate such as R&D spending; human resources; new ideas and concepts; external knowledge sources
Enablers	Major tools/strategies employed to realize innovation such as collaborative partnering; supportive work environment; leadership; commitment; knowledge management practices; reward schemes; innovation policy
Barriers	Primary factors that inhibit innovation such as unsupportive organizational culture; lack of financial resources; unwillingness to change; financial risks; temporary nature of projects; lack of collaboration among project partners
Innovative activities	New or improved products and processes such as energy efficient materials; integrated design; off-site manufacturing; lean construction; automation of processes; information and communication technology (ICT); new organizational methods and relations
Benefits	Major outcomes of the innovation process at project level such as increase in productivity; decrease in cost and duration; improvement of product quality; improvement of client satisfaction
Impacts	Major outcomes of the innovation process for project participants such as improvement of human resources; better company image; market penetration and growth; increase in technical and organizational capability; productivity; decrease in cost and duration; improvement in product quality; future business collaborations with project parties

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would comply with the design objectives were scarce and expensive. The team had difficulty finding the right supplier. One of the key decisions in the project was to work with a supplier that was experienced in steel structures, to develop the timber frame solution. This resulted in an innovative, environmentally friendly hybrid timber-steel structure that also proved to be cost effective.

The client acted as a leader in the project and created a supportive work environment for new ideas. Among the primary enablers of successful delivery of this project was the strategic partnering approach. The contractor conducted R&D on behalf of the client and allocated specific expertise to invest in developing new solutions for the client. A key aspect of this project was the store being a blueprint for future stores. Therefore, knowledge and experience gained throughout the project, starting from the design to construction and operation, were critical. The partnering approach throughout the supply chain and the repeatability of the project was an important element in ensuring the diffusion of introduced innovations. The contractor also benefitted from the buying power of their partnering client, which was critical to achieve the cost effectiveness of the energy efficient products.

The client's commitment to carbon reductions, through the combination of new technology and good business, led to dramatic reductions in carbon footprint. The carbon footprint of the developed eco-store is 70% less than an equivalent store built in 2006. The contractor received a BREEAM "Very Good" rating with this project. BREEAM stands for Building Research Establishment Environmental Assessment Method, which is an environmental assessment method and rating system for buildings in the UK. The project has also contributed to the quality of local life. The scheme employed 40% of its staff from locally unemployed people. Finally, the project parties gained experience in energy efficient technologies, which may be exploited in future projects.

Case 2: Eco-Residences Project

The eco-friendly student accommodation was a replicable model that has been designed to increase awareness among students about sustainability. The UK's Higher Education Funding Council (HEFCE) guidance on universities' environmental performance provided an important benchmark for the innovations achieved in the project. HEFCE has announced that, from 2011, all capital funding will be subject to institutional carbon management plans, and further, that pursuant to the Climate Change Act, the higher education sector is likely to be set a target of reducing carbon emissions by 80% by 2050 (HEFCE 2009). The CfSH has also been influential in this project. Furthermore, the university's own desire for the adoption of sustainable practices played a major role.

Among the key ingredients in the successful delivery of the project was the effective use of a partnering approach. The university selected a residential developer as partner to design, build, fund, and manage its eco-friendly accommodation under a 48-year contract. The architect of the project prepared a bespoke design, adopting the "sustainable by design" concept of a Canadian academic. A partnership within the university was established to help increase recycling rates, reduce toxic waste, reduce energy consumption, and green the university's supply chain. The partnership has also aimed at involving the end users (students) in the process to better understand their requirements early in the design phase.

The key features of the sustainable by design concept focus on a simple design delivering high energy efficiency and heat recovery. A closed panel timber frame was chosen to achieve sustainability. Prefabrication was a major factor in keeping costs and waste to minimum. Both the structural timber frames and bathroom pods were built off-site and delivered ready for immediate installation and connection. The project team identified that the maximum benefits of MMC would only be achieved through the application of lean principles on which they received consultancy. Just-in-time (JIT) delivery, as a part of lean production, was fundamental to maintaining the construction program.

Panelized timber frame construction was new to some members of the construction team. The inexperience and conservative behavior of the contractor was an obstacle in the innovation process. To overcome those issues, seminars and project meetings were held at an early stage to familiarize the contractor and supply chain partners with the approach and construction technology involved.

Measures were also put in place to monitor and provide information on energy use as a means of directly involving the students with the ongoing operation of the building. Each unit was fitted with a building management system (BMS) that constantly monitors and communicates utility use. A competition was launched to promote and incentivize reduced water, gas, and electricity usage, and to reward the residences with the lowest carbon footprint. Cost savings were reflected on the rents, which has been an additional benefit to the students.

Among the benefits achieved by the project are: (1) reduction of costs by 10% per student room in comparison to the previous phase of residences; (2) reduction of student rent by 15% against the rental charges in the previous phase; (3) reduction of annual CO_2 emission by 20% per student against design criteria set by the building regulations; and (4) reduction of gas consumption by 5–10% per student room compared to the previous phase. In addition, minimization of construction impacts were achieved by the construction contractor through a variety of measures, including site utility monitoring with targets for electricity and water, a construction site waste management plan, and the use of reusable hoardings and eco-cabins for on-site accommodation. The project received a BREEAM "Excellent" rating for its environmental design. Another key impact of the project has been reputational, with the university seen as a leader in terms of environmental design and construction.

Case 3: Estate Regeneration Project

The estate regeneration scheme delivered over 500 units of new housing as part of the vision for a sustainable future in the town. The client of the project is a housing association that owns and manages homes across the UK. Building regulations on social housing had a great impact on the processes and performance of the project. The CfSH requires contractors to use innovative products in their construction processes to deliver the specified sustainability performance levels. Funding conditions set by the UK Housing Corporation promoted the increased use of MMC in social housing, particularly off-site manufacturing (OSM), as a key method for promoting sustainability within the construction industry. Based on the client's R&D and experience in similar projects, timber frames were identified as a means of delivering several advantages, such as the pace of construction, quality of the units, lower cost, enhanced thermal performance, and reduced carbon emissions (Reynolds and Enjily 2005). The client also introduced the idea of using closed timber frames to achieve sustainability.

The client devoted resources to deploy new technologies and techniques, ranging from renewable energy sources to MMC, to create cost-effective solutions. The client also employed consultants to aid in the development of methods and procedures to improve site processes. They decided to work with the contractor to eliminate the initial cost barriers to MMC to gain long-term benefits. One of the most important ingredients of a successful regeneration project is the involvement of the local community.

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Residents were heavily involved in the development of each scheme in the project. Project team members tried to establish positive working relationships with the local community and to better understand the needs of the affected residents.

The closed timber frames were used as the structural elements of the superstructure. By using MMC, the closed timber framed and paneled units went from ground floor slab to panels in place in just 12 weeks, which is half the time of similar traditional builds. The wall panels and floor cassettes were delivered on site, with windows and doors already fitted in the factory.

The client had identified lean construction as a potential innovation during their R&D on MMC. Lean construction can save time and cost through eliminating waste and achieving continuous improvement of site processes (Koskela et al. 2002). The client employed a lean construction consultant. The team focused on identifying the activities causing waste; they standardized the finishing processes and reduced wastage of materials on site in addition to wasted operations.

Among the barriers to adopting MMC and lean construction were primarily the inexperience of the work force and resistance from the contractor's employees. Another problem was related to the unavailability of advanced products, and to the reluctance of most of the suppliers to work on them as a result of increased cost. Partnering provided the basis for the project participants to adopt a win-win approach to solve problems and foster synergistic teamwork, as suggested by Barlow et al. (1997). The client and the contractor agreed to invest jointly in lean construction. The trust and good communication created through partnering allowed the joint utilization of resources. They managed to set up a partnering agreement with a timber frame supplier that had invested in R&D on environmental sustainability and that could produce the required products.

As Tatum (1989) suggests, one of the key management actions for successful innovation is leadership. In addition, Farid et al. (1993) add that positive attitude and open-mindedness of managers encourage creativity and innovation. In this respect, the managing director of the contractor organization has shown effective leadership in creating a company culture to facilitate innovation. An "Innovator of the Month" scheme ensured that all staff were aware of the importance of innovation and had the opportunity to contribute. This was supported by the idea of chairman's lunches to firmly establish the fact that no hierarchy or monopoly existed in the generation of ideas. Another initiative was to exploit external sources by establishing so-called "Innovation Circles" (Lu et al. 2007), which bring the supply chain members together in an open approach to share ideas and tackle problems.

The productivity and sustainability improvements were measured by the project team by comparing two similar phases (in terms of size and type), one traditionally built and the other based on MMC and lean construction. According to their measurements, achievements of MMC included reduction in construction waste by 50%, noise level by 50%, meter square costs by 7%, total unit cost by 3%, timber frame costs by 16%, and project duration by 6%. There were also benefits for local residents, with reduced levels of vehicle movements and noise. The development received a rating of "Good" in the BRE eco-homes accreditation. The contractor gained experience on MMC and lean principles, which can be applied to future projects.

Case 4: Coastal Defense Scheme

The project was designed to improve flood protection and to upgrade the associated promenade to provide a public space and reenergize the area. The project was the first partnering contract and the largest civil engineering project undertaken by its council. The council also registered the project with the CE as a demonstration project. With the intention of capitalizing on the benefits of partnering and delivering best value, the council replaced its old price-based competitive tendering with a quality driven process. Under this system, 26 contractors were assessed through a three-stage selection process that evaluated experience, financial stability, commitment to health and safety, employee skills, and references from clients, subcontractors, and suppliers.

Increased integration and trust-based cooperation through the early involvement of contractors is believed to help team members achieve efficient and value-adding solutions (Barlow et al. 1997; Briscoe et al. 2004). The selected contractor was given the opportunity to contribute to the design stage of the project. At the start of design, a partnering charter was produced to commit all partners to deliver a quality scheme for the public; achieve an exemplary safety record; ensure the achievement of best value for the budget at all times; communicate effectively with all those involved or affected by the scheme; and be considerate to the community and to the environment.

A design competition was undertaken for the selection of the architect to prepare a master plan. Four designs were developed and subjected to consultation, both with local people and statutory organizations, i.e., the Environment Agency, to ensure that the works were sympathetic to the needs of the community and environmentally acceptable. The designs were also reviewed by the contractor for budget compliance and buildability. A joint decision was made in choosing the final design.

Because of the challenging working environment, coastal protection schemes carry inherent risks during construction. Maximizing productivity during tidal windows was critical to the success of the project, as was reducing the potential risk of damage to sensitive marine eco-systems. Solutions such as a purpose built precast facility were codeveloped by the team. The R&D team worked on designing and producing precast concrete units that would offer a safer, more cost effective, higher quality, and more sustainable alternative to traditional solutions, such as rock armor or in situ concrete. The team worked with a university to obtain the technical information to better understand coastal processes. The contractor's work experience in the area helped the team find cost-effective solutions to the technical problems encountered throughout the project. The project's web site, weekly design meetings, and steering group meetings were used to ensure effective communication among the project parties.

Precast units were manufactured by using a high strength concrete in a purpose built facility five miles away from site. This allowed the team to take advantage of established manufacturing techniques, such as JIT delivery and lean construction, which resulted in less waste and higher efficiency. Because the concrete was precast off-site, there was no risk of washout from unset concrete. In addition, a reduced number of vehicles were required on site. Several low energy and renewable technologies were used on site, including wind turbines providing power back to the national grid, solar panels providing power for heating and lighting in the shelter areas, and LED luminaires providing energy efficient lighting.

To ensure that the community involvement continued through the life of the project, an interest group was established with the inclusion of local residents, community groups and representatives from retailers, leisure facilitators, hotels, restaurants, the police, and commercial bodies. Its aim was to work with the council and the contractor, to identify any potential problems early on, and to continue providing input throughout construction. Empowering the community was a key innovation of the project because it helped

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the partners achieve an exemplary scheme. Local people were employed where possible. In total, 75% of staff on the scheme lived within approximately 55 km (35 mi) of the site and 76% of suppliers were located within a 40 km (25-mi) radius.

The team achieved high level client satisfaction and finished the project on time with a 5% cost saving. It also improved on health, safety, and environmental performance. The scheme itself received many regional and national awards. It also exploits the assets of the natural coastal heritage, helping to create a sustainable tourism destination.

Discussion

Based on the preceding analysis of the four case studies, each component of the innovation framework is discussed in the following:

1. Types of innovation: the use of MMC and lean construction has been the most common type of process innovation in the investigated projects. Precast concrete units, timber frames, and hybrid (steel-timber) structural frames were observed to be the innovations of the products.

   In addition to dealing with product and process innovations, this research also concerns organizational innovation, which has not been adequately examined in earlier studies. End user (local community and student) engagement, starting from the design through the operation phase of the facilities, has been an example of organizational innovation. For instance, with public satisfaction a prime concern in the sea defense project, public engagement started in the design phase and was maintained afterward. This was also evidenced in Barrett's (2007) work, which stated that project teams aiming at engaging end users from the early phases of projects designed for public use are more likely to achieve end user satisfaction.

   Similarly, in the case of the eco-residences, the innovative student involvement in carbon reduction during the operation phase was enabled through the carbon competition. This shows that innovative activities are not limited to design, production, and construction but can be also extended to the operation phase. A wide range of innovative activities observed in this study also reveals the potential of the construction industry to innovate.
2. Drivers of innovation: a common root of innovation in all four cases was the environmental sustainability issue. As a response to climate change and its effects on the environment and energy consumption, there has been a growing emphasis on corporate sustainability. This is reflected by pressure exerted by clients, government, and other stakeholders for the industry to be more accountable for its environmental impacts (Thorpe et al. 2008), with the UK being among the examples of government-led initiatives in terms of energy consumption regulations and policies (e.g., CfSH and HEFCE).

   The clients' positive role (either public or private sector) in terms of environmental sustainability and innovative activities has been clearly observed in the case studies. This research supports the findings of earlier work that reported building regulations and client requirements as the major drivers of innovative solutions in the construction sector (Brandon and Lu 2008). It also provides evidence for the assertion of Kulatunga et al. (2011) that clients promote innovation in construction projects through their championing characteristics including proactive involvement, information dissemination, and effective coordination.
3. Inputs of innovation: because they were committed to delivering best practice and achieving innovation, all teams in the four projects invested financial and human resources to develop and implement new ideas and practices. Previous experience, R&D, consultancy, knowledge sourcing from universities, and end user input were used to develop the innovative solutions. This finding provides evidence that not only internal sources, but also external sources, are essential for idea generation and development, as Veshosky (1998) suggested in the study dealing with innovation information management. This further indicates that joint effort is required to innovate in construction; collaboration among project members is an essential ingredient.

   Another observation is that R&D activities took place in each of the case studies, but only in one was it identified and officially registered. Construction professionals see R&D as a part of their project management practice and do not consider it to be a specific effort to produce innovations. Because R&D expenditure is one of the primary indicators of innovativeness, construction is considered to be a low innovating industry. However, this might be improved with companies registering their R&D expenses.
4. Barriers to and enablers for innovation: innovation is difficult to achieve; it requires investment, commitment, and change in organizations and processes. In terms of product and process innovations, some of the team members were hesitant as a result of the additional costs, inexperience of the workforce, resistance to change, and unavailability of the required products. However, those barriers were primarily overcome by the integration of the project teams. As suggested in the literature, successful innovation often requires effective cooperation, coordination, and working relationships between the different parties in construction projects (Tatum 1989; Gann and Salter 2000; Ling 2003; Blayse and Manley 2004; Robichaud and Anantatmula 2011). In this research, this has been evidenced in several ways. For example, strategic partnering between the clients and the contractors, early involvement of contractors, and supply chain partnerships helped the teams to build trust and become committed to innovation.

   Repeatability of the projects was another influential factor because the benefits of innovations can be reaped in the long term rather than the short term. Also, organizational innovations that included end user engagement did not face resistance from the project stakeholders. As long as end user input was sought, communities were willing to collaborate. The significance of stakeholder input in shaping the project in its early stages is also emphasized in the work of Robichaud and Anantatmula (2011).
5. Benefits of innovation: improvements in project performance were observed in many ways. First, most of the projects proved to be cost effective, despite the initial consultancy and R&D cost incurred. Additional cost savings in future projects will also be possible based on the gained experience. Furthermore, the teams reduced completion times, improved quality, health and safety, minimized waste, and reduced carbon emissions. Different benefits might accrue, depending on the project objectives. For instance, innovation might bring financial benefits in one case, whereas it might only improve environmental performance in another. The extent to which an innovative activity is successful should be measured against the initial targets set by the project teams.
6. Impacts of innovation: outcomes of innovation have also been observed at a broader level. Positive impacts of innovation include enhanced corporate image, recognition through regional

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Table 3. Innovation Components of Case Studies

Case	Drivers	Inputs	Innovative activities	Barriers	Enablers	Benefits	Impacts
I	Client's requirement for a cost-effective, high quality, and repeatable eco-store; client's drive to improve energy efficiency; CfSH	Technology center within contractor (as a consultant); joint R&D by client and contractor	Hybrid timber frames; low energy and renewable technologies	Unavailability of products; cost; Reluctance of the suppliers; conflicting interests of project parties	Strategic partnering between client and contractor; supply chain partnership; repeatability of the project; client's commitment to sustainability	Cost-effective and repeatable design; reduction in carbon emissions; BREEAM "Very Good" rating	Quality of life; local employment; experience in energy efficiency; regional awards
II	Client requirements for eco-friendly and affordable accommodation for students; HEFCE guidance; CfSH	Sustainable by design concept; R&D and consultancy on lean construction	Closed panel timber frames; energy efficiency and heat recovery; BMS	Inexperience of the contractor in timber frame construction; conservative behavior of the contractor	End user engagement; long term partnering with residential developer; commitment to innovation; seminars and project meetings; JIT delivery	Sustainable and cost effective design; reduction in carbon footprint; minimized waste; lower rents; BREEAM "Excellent" rating	Experience in energy efficiency; example residential scheme; reputation for the university; knowledge transfer to inform future projects; regional awards
II	Client's aim to increase awareness about sustainability among students	Student input into design process; environmental research centers of the university	Partnering with students throughout the project; carbon competition among students	No barriers were observed	University's vision and commitment; partnership within the university; willingness of the students to collaborate	Sustainable and cost-effective design; reduction in carbon footprint; improved social space	Student satisfaction; awareness among students; example residential scheme
III	Funding conditions of housing corporation; CfSH; Client's requirement for MMC and lean construction	R&D by the client; joint lean construction consultancy; local community input	Closed panel timber frames; lean construction; waste minimization	Inexperience of the work force; resistance from the employees of contractors; unavailability of products; Reluctance of the suppliers	Partnering between client and contractor; cost sharing for consultancy; supply chain partnership; contractor's initiatives (i.e., innovation circles); effective leadership of the contractor	Minimized waste; reduction in cost; reduction in duration; BRE eco-homes "Good" rating	Experience in MMC and lean construction; example regeneration scheme; knowledge transfer to inform future projects; regional awards
IV	Project risks; client's requirement for energy efficient solutions; client's aim to achieve demonstration project	R&D by the client and contractor; contractor's previous experience; knowledge from a university	Precast concrete manufactured off-site; low energy and renewable technologies; JIT and lean construction	Unfavorable ground conditions; Cost	Early contractor involvement; integrated teams; local suppliers; partnership with the supplier, designer; project website	Demonstration project; reduction in cost; improved health and safety, environmental performance	Regional awards; future collaboration along supply chain
IV	Client's vision to provide a public space; regeneration of the area	Interest group by local people	Partnering with wider community throughout the whole process; use of local press and radio	No barriers were observed	Willingness of the community; employment of local people	Public satisfaction; good and safe neighborhood	Tourist attraction; income generation; national recognition

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and national awards, future collaboration along the supply chain, experience in MMC and sustainability, knowledge transfer to inform future projects, client and end user satisfaction, and improved quality of life for local people. Innovation does not only serve project objectives, but also benefits the participating organizations in the long run. Therefore, construction professionals should not be reluctant to innovate or discouraged by the initial challenges and additional costs incurred.

A brief summary of the innovation process in each case is presented in Table 3, which summarizes the most influential factors in achieving product, process, and organizational innovations.

Conclusions

The effective analysis of innovation is important to achieve benefits at all levels, including project, firm, and sector. In the context of this paper, a framework was developed and employed in four case studies to explore the components of the innovation process in construction in project settings. The research proposes a novel way of analyzing innovation: it first investigates innovation at the project level and then adopts a systemic view of the innovation process by analyzing the interacting components that emphasizes the interorganizational nature of construction innovation.

Several conclusions can be drawn from the developed framework and case studies. First, construction companies do not usually innovate on their own. Clients play an important role in both creating the project conditions in which innovation can flourish and in understanding and communicating end user needs to the project team. The second conclusion is related to overcoming innovation barriers. The construction industry seems reluctant to invest in new methods of construction, because changing the traditional way of working is challenging and the return on investment is not guaranteed. However, long-term procurement relationships, collaborative working, and early engagement in projects are effective ways of developing trust among parties and thereby facilitating innovation. Additionally, management support is essential to break employees' resistance to change.

The third important conclusion of this study concerns innovation management. More systematic management of innovation activities can bring benefits at both project and corporate levels. For example, financial benefits based on tax incentives may be obtained through registration of R&D activities. Partnering agreements can provide cost-effective innovative solutions. Additionally, company policies supporting creativity among employees can lead to ideas that improve project and corporate performance.

Finally, innovation performance should be measured with respect to innovation objectives, without being limited to standard project management performance criteria. Much of the innovation focus revealed by the case studies is environmental sustainability. Therefore, innovation performance should include measures related to environmental drivers, just as other project objectives. For example, reduction in waste, energy consumption, and carbon emission should be considered to be significant measures of innovation, just as much as reductions in cost and duration. In addition, the wider impacts on project participants should be taken into account when assessing the success of innovation. Contribution to local life and knowledge/experience acquisition are important indicators of long-term success of organizations.

This study presented a framework to analyze construction innovation and demonstrated its use with cases from the UK focusing on energy efficiency issues. The framework may also be employed in other settings. Further case studies will enrich the factors discussed in this study. In addition, a statistical study may be useful to examine the degree these elements influence the rate of innovation in construction. Similar studies can be also conducted in other project-based industries.

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