Realising offsite construction and standardisation within a leading UK infrastructure consultancy

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Abstract
The civil engineering sector is often regarded as resistant to innovation and to the implementation of new ideas. With the UK public sector increasingly adopting the 'more for less' approach towards project financing, the sector needs to continually adjust in order to meet clients' evolving demands.
Offsite construction and standardisation (OSS) has been shown to be a key solution for the building and housing sectors, which have increasingly embraced such methods over the last decade in order to help increase efficiency, raise quality and reduce costs. OSS is nowadays employed in many large scale building projects varying from hotels and hospitals to prisons and student accommodation. Certain aspects, such as precast concrete elements, have also been widely employed in the infrastructure sector, but other applications have had little deployment.
A series of initiatives are currently taking place in order to modernise the UK construction industry, with a governing aim of reducing project costs through improved resource and data management. The use of offsite construction methods and standardisation have been deemed equally appropriate approaches for reducing costs and construction time, while increasing construction quality. This paper reports on a research initiative at a leading UK infrastructure consultancy to examine current practices regarding OSS. Through semi-structured interviews with senior managers from different industry sectors within the company, opportunities for future offsite implementation are identified. The findings identify research and industry potential for improving "*offsite mature*" sub-sectors such as bridges, increased implementation of offsite techniques in the water and maritime sectors, as well as discussing sub-sectors such as tunnelling, which appear to be moving away from offsite construction.

Keywords: offsite, standardisation, infrastructure, consultancy, innovation

Introduction
In the current economic climate the construction industry is under extreme pressure to minimise costs and increase efficiency. Being 8.5-10% of UK's GDP and comprising 300,000 firms employing 2-3 million people (BIS, 2012), the construction industry has a significant impact on the UK economy. The variations in these numbers are related to how precisely one defines the "construction industry".

To increase competitiveness and align strategy with government benchmarks, many firms have moved towards more innovative construction approaches, challenging their processes with the objective to minimise cost whilst sustaining healthy margins. Every part of the supply chain is addressing the challenge accordingly. This paper focuses on the drivers and constraints within a leading UK infrastructure consultancy which arise when implementing increased offsite construction and standardisation (OSS) in its decision making processes and design methods The case study addresses a gap in the literature, by focussing on civil engineering, sub-dividing the sector further before examining each sub-sector individually, identifying factors affecting innovation and allowing potential for offsite solutions to flourish.

Background

Improving efficiency in construction has been on the agenda of government and industry for many years (Wolstenholme, 2010). Various attempts have been documented, which address different aspects of the construction industry (Figure 1). One of these high impact reports includes the Emmerson (1962) report which surveyed the "construction industries" and presented problems that restrained improvements. Closely following there was Banwell (1964) who focused on contractual management and promoted "early contractor involvement", increasing collaboration across the supply chain. The Egan (1998) report stood out from previous reports: Green (2011) argues that the industry adopted few, if any points from the Latham (1994) report, but quickly proceeded to integrate Egan's novel construction culture, which suggested drastic transformation rather than incremental improvement. Notwithstanding, most of the points underlined by many of the reports listed above have yet to be fully addressed and are still considered by many to be challenges to construction efficiency.

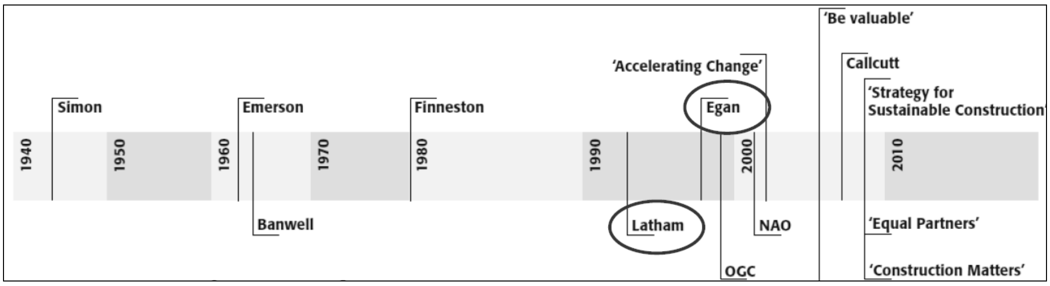

Figure 1. Construction industry reports over time (Wolstenholme, 2010)

As every construction generation had a government report tackling inefficiency, each one also had a buzzword and benchmarking factors; for example 'Total Quality Management (TQM)', 'Just-in-time (JIT)', Lean, Standardisation and Preassembly (S&P), 'Design Quality Indicators (DQIs)', and 'Key Performance Indicators (KPIs)' (du Gay and Salaman, 1992, Sayer 1986).

Numerous in-depth research projects have attempted to identify the boundaries of the construction industry (Ive and Gruneberg, 2000, Hillebrandt, 1984). Historically there has also been an evolution in the way influential government-led reports portray construction from 'construction industries' (Emmerson, 1962, Banwell, 1964) to "the construction industry" (Latham 1994, Egan 1998). It is commonly agreed that the construction industry can be split into sectors or sub-industries, with the two most prominent being building and civil engineering (Green, 2011). Despite most of these initiatives aiming at the whole construction sector, the majority of industry applications and academic research projects have been aimed at the housing and building sectors (Pan et al., 2008). According to Green (2011) the civil engineering sector has had an "overriding tendency" to invite outlandish management techniques, and then portray such methods as a vital factor of best practice. In addition, the term best practice has an equally elusive meaning, which adds to the inclination towards the promotion of current "management recipes" (Burns and Stalker, 1961). These innovation formulas targeting the construction industry are commonly distilled from epochal "fashionable" management techniques rather than scientific or academic evidence. There have been a series of examples where management or design methods were initially identified as successful. Methods from other industries were "made" generically relevant via theorising their fundamental principles and then introduced for adoption in the civil engineering sector (Brensnem and Maeshall, 2001).

A series of attempts have been made to identify what drives and hinders innovation in construction (Bossink 2004, Blayse and Manley 2004, Koskela and Vrijhoef 2001,Vernikos et al 2011). Green (2011) argues that the civil engineering and infrastructure sectors have a segmented composition that does not allow straightforward implementation of "management panacea" from other industries. In addition, the construction sector is allegedly renowned for its "regressive attitudes" and "adversarial culture" (Fernie et al, 2001). This may be factual in specific parts but cannot describe the industry as a whole, since the term 'innovation' is variably perceived and defined depending on the standpoint of the individual in the supply chain (Vernikos et al, 2011). Furthermore, the continually changing imperatives in the industry possibly pose the greatest barrier to innovation. Therefore, even if one agenda provided a focus for all parties interested in improving the industry, it has been shown that the focus shifts due to the "broader policy environment" driven by the highly influential government objectives (Green, 2011). These reports urge all parties to adopt and evolve, thereby increasing efficiency. Nevertheless, the inefficiency in one level of the supply chain gets passed on from the consultant to the contractor and thereafter to the sub-contractor and vice versa. The process minimizes the risk of being accused as "non-innovative" but with no real increase in efficiency output.

Conversely, offsite methods and standardisation have been employed in the UK construction industry for many years (Gibb, 1999) and the market was valued at £2.2bn by 2004 (Goodier et al, 2004). The advantages of OSS have been thoroughly examined (Gibb, 1999, Parry et al, 2003, Venables et al, 2004) and they predominantly include improvement or better control over cost, time, quality, health and safety, risk and sustainability. The results aim to increase profits, client satisfaction and whole life costing (Pan et al, 2008).

Research Design and Methodology

To examine the drivers and constraints that arise when implementing increased OSS in design consultancies, the methodology employed was a qualitative case study with quantitative analysis of secondary supplementary data, where available, for triangulation and conformation of findings. The research design was predominantly based on the Eisenhardt (1986) approach focussing on capturing the dynamic research potential of offsite innovation in an organisation by using multiple levels of analysis within a single study. Tools applied included literature review, questionnaires, focus groups and interviews.

The design consultancy examined was split into a series of market-facing teams. The literature review commenced with an overall analysis of the innovation trends that impacted the construction industry, followed by a brief analysis of barriers to offsite and innovation in civil engineering. The literature review was ongoing through the research period. Six times a questionnaire was used to conduct an initial scoping pilot study, allowing identification of the appropriate and most relevant staff prior to in-depth research. The questionnaires were emailed in July 2011. The following six interviews aimed to identify drivers/barriers to OSS, perception of offsite and potential development opportunities and innovation. An interview question pro-forma was used to ensure consistency. The interviews were semi-structured and so the pro-forma was only loosely followed. The interviews took place in October-November 2011. Finally, two focus group discussions were held to analyse the innovation opportunities. The focus groups took place in December 2011.

All verbal communication with the consultancy staff, whether for formal data collection or brief informal meetings, was recorded and transcribed. Triangulation of data took place in the relevant sector team where in depth records were kept, allowing project case studies and project reports to be examined. The data collection strategy employed allowed the filtering of information from general senior management to sector specialist within each area. This minimised the risk of overlooking relevant knowledge pools within the consultancy under review.

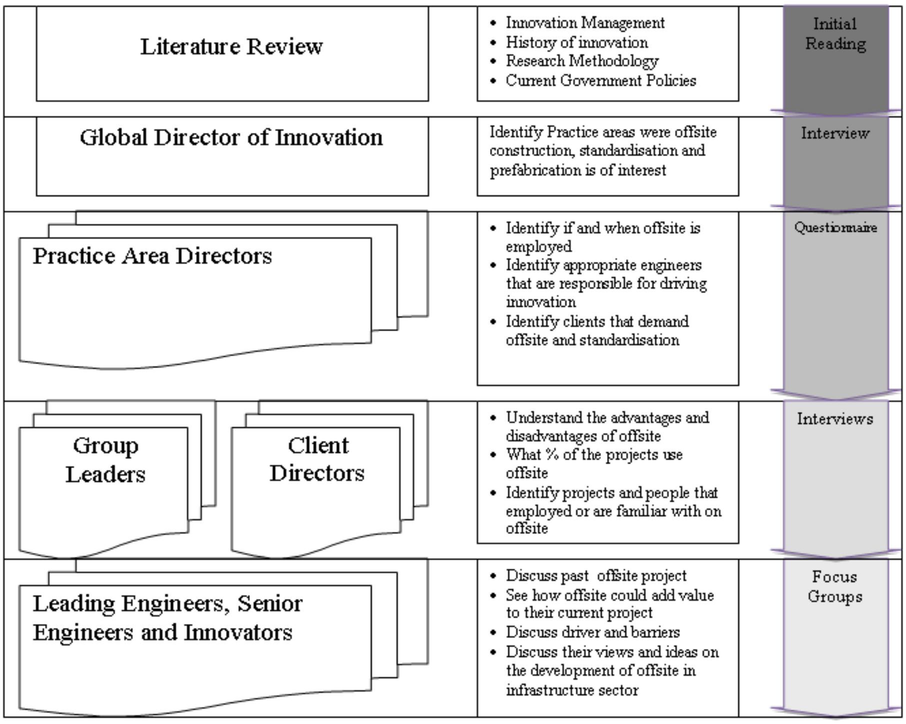

Figure 2. Research Design

Theoretically, empirical data is rich in detail and testable but lacks wide perspective. Therefore, conclusions may be narrow and idiosyncratic due to the vivid, voluminous information (Eisenhardt, 1989). When collecting data within a corporation, the individuals interviewed may represent the sector through seniority but not necessarily reflect accurately the whole perspective. Perception is also affected by recent education, past career experience and involvement in recent projects.

Data Collection

The research had direct input from 20 staff in total, including one global director, six directors, two client directors, eight group leaders and three senior engineers. The research design (Figure 2) demonstrates the way information was distilled in order to identify innovation opportunities. This process ensured that all relevant staff were informed and contributed to the research initiative.

Findings and Analysis

The findings focus solely on one leading UK design consultancy and are based on a qualitative case study research. The findings are not drawn from statistical analysis and therefore do not represent the civil engineering industry as a whole. The analysis is based on Eisenhardt's (1989) approach to building theory from case study research.

Maritime

In the maritime sub-sector the offsite business is estimated at around 30-40% of all works. The main advantages of offsite solutions identified were the speed of construction and a more environmentally friendly installation. It was made clear that contractors usually drive the design based on their past experiences and the type of equipment both in their possession and in proximity to the project. Benefits of precast include environmental aspects, quality control, health and safety and reduction of commercial risk. One of the main drivers for the use of precast concrete in coastal projects is that the majority are design and build and hence the project team can take full advantage of the potential quality and speed of construction benefits of precast concrete. With offsite, design teams can plan and organise the supply chain more efficiently, but this puts pressure on the designers to *"finish their designs very early"*. The risk is that, after the fabrication process commences, the client may change its mind and the contractor may end up with numerous redundant precast units, incurring additional costs. However, there are examples where contractors would manage to fit these unwanted units into other projects.

Cost varies considerably, depending on the country where the project is located. Some countries in the Middle East have extremely cheap labour and where local natural rock armour is not available in the scale needed, concrete is employed. Depending on the local labour cost or other factors mentioned above, either precast or insitu concrete is used. Additional factors concern the cost of materials "*in Australia the cost of concrete is higher therefore it is sometimes cheaper to ship huge precast units from Asia (4000 miles) to Australia because it may cost less"*. In the UK, rocks of the required size and quality may be available from quarries nearby, or precast units may be able to be sourced. However, if such units were not able to be delivered by sea, these solutions would be considered impractical and units would typically be shipped from other countries such as Norway.

The maritime/costal sector experiences unique drivers and constraints because of the scale of the products and the availability of the main transport route: the ocean. A significant factor is the depth of the water around the construction site. A significant barrier to offsite precast usage is the planning constraints due to their "*industrial look"*. The UK government agency responsible for the environment prefers natural rocks to either insitu or precast concrete units. In other parts of the world, such as the Middle East, precast is the norm. In the UK maritime and costal sector OSS is still considered by many as an innovation. Different countries have different drivers and barriers. "*The calculation of logistic costs is a grey area*". Transport providers keep costs a commercial secret and it is difficult, even as the client, to acquire a breakdown, particularly as there are only four or five leading logistics contractors globally and they influence the market.

Bridges

With bridges, contrary to other sub-sectors, the potential of offsite is assessed for every component. This research focused on small span cases that represent the majority of the workload rather than large, high profile projects. Furthermore, long span projects allocate a large budget for developing innovative solutions which do not represent the bridge sector as a whole.

"Precast concrete columns and beams or steel products are commonly used. […] It is common for 30-40% of every structure or project to be offsite; it really depends on the scale of the project and the type of bridge". This is the highest average percentage in comparison to all other sectors of the case study. The offsite bridges market can also benefit from an increase in lighter materials with improved structural properties, such as fibre-reinforced polymer composites (Bakis et al, 2002). The benefits of offsite identified by the interviewees reflect all those identified in the literature. Offsite in bridge projects is recognised as improving safety by minimizing work on site and increases the speed of construction. It also contributes to cost reduction directly by designing more cost effective structures and indirectly by minimizing disruption, including reduced penalties, minimizing time and complexity sometimes just by installing bridges in one piece, if local regulations permit.

The design and method of construction are governed by project limitations. "*In most sectors the design is cost driven (but) in bridges it is usually limitations driven".* These limitations vary geographically and directly affect the percentage of offsite construction in a project. Examples include: logistical limitations such as a small and inaccessible road network which prevents the transportation of large components; and cultural perceptions of what are considered acceptable materials, such as " *steel, which currently is available in all Asian markets , is disliked because they see the maintenance works as a hazard and liability"*; Finally, the perception of risk and health and safety is also a great limitation especially within the Asian markets.

Rail

Rail is a sub-sector that works collaboratively with other sectors, such as bridges, tunnelling, buildings and asset management. Therefore, it is difficult to identify the precise percentage of offsite used in the sector, due to its collaborative and segmented nature. Furthermore, the consultancy is involved in a series of projects that focus on mechanical and electrical aspects, such as rolling stock that are not relevant to offsite. Technological improvements in automation have allowed work to be mechanised and have reduced cost and health and safety risk especially in track maintenance.

The predominant benefits of offsite construction identified include the improvement of health and safety and also a reduction in construction time and cost. Therefore, offsite solutions are commonly assessed. It was acknowledged that the rail sector can learn from other sectors and with rail currently flourishing in the UK, the potential for innovation is great.

Tunnelling

Similar to Rail, tunnelling is a segmented sub-sector. Parts of the sector such as micro tunnelling have been using offsite construction inherently for many decades (Chung et al, 2004). From the definition "*machine-made tunnel too small for a person to work in*" (Scott, 1991) it is clear that prefabrication was the norm for micro tunnelling and pipe jacking. Nevertheless, with the development of larger capacity hydraulic jacking equipment and higher strength materials, it was possible to use this method to fabricate short length road tunnels. These segmental tunnelling techniques are considered innovative (Ogborn et al, 2010). They are commonly used when a link is needed between two points but disturbance to the overlaying asset is unacceptable or must only be very limited (Ogborn et al, 2010). The longest segmented tunnel in the world was completed in August 2011 in the UK reaching 126 m (Smith, 2011). Segmental tunnelling is a great example of offsite construction but, as it is considered extremely costly, it is employed only when other options cannot be used.

When considering conventional tunnelling, offsite construction is mainly used for bored tunnel linings, including segmental precast concrete or cast iron rings. Overall advantages include structural stiffness (Deming and Houmei, 2000) and quick mechanised installation in bad ground conditions and enhanced quality and durability. The installation is made exceptionally easy with sophisticated automated tunnelling machines. Nevertheless, in *"the last few years we are able to increasingly improve and control the quality of material such as gunite and shotcrete, considering also the technological development of spraying nozzles we are using less offsite than we used to"*. The decision is made following a cost-benefit analysis with the governing factor being the length of the tunnel. Tunnelling machines are large and expensive, therefore they are considered primarily for long tunnels with bad ground conditions.

An emerging tunnelling practice that is currently employed by the design consultancy is immersed tube. This technique enables engineers to link areas that are kilometres apart, yet allow open shipping lanes at the surface (Gursoy, 1997). Immersed tube is a competitive solution when compared with bridges and bored tunnels. Reinforced concrete units can be 100 m long, fabricated in dry docks and are sunk into a pre-dredged trench (Lo and Tsang, 2008). This type of tunnelling was not discussed during the interview because it does not represent the sector's norm. It is a bespoke solution which, although it has been used in a few projects, is still a niche area globally.

To conclude, in conventional tunnelling, the data from this case study indicates that offsite construction is decreasing. Nevertheless due to technological advancements in hydraulic jacking new techniques are prevailing for highways and rail projects.

Urban Water

The urban water sector deals with integrated water management, outfalls/intakes, solid waste management, urban water asset management, wastewater engineering, water process and water supply engineering. During the past year UK clients have been increasingly demanding options that will bring construction cost down. Offsite has been assessed as a proven method of increasing construction efficiency. The senior staff, aiming to sustain the firm's competitive advantage, is theoretically aware of the benefits of offsite as portrayed by the literature. Offsite solutions, such as pipe jacking and reinforced concrete manholes, have been used in the past but they are not considered to be innovative. More recently, modular solutions for assets such as pumping stations have entered the market. The urban water sector is an emerging offsite market which has great potential for development.

Water and Environmental Management

The water and environmental management sub-sector works include canal and inland waterways, dams/hydropower, flood risk management, groundwater, mining, hydraulic modelling, integrated river basin planning and irrigation/drainage. The offsite construction benefits identified focus on improved environmental impact control and cost reduction. Similar to the urban water sub-sector, the clients consider that the supply chain could deliver its programme far more efficiently if standard designs were used that could be "*pulled off the shelf"*" depending on the type of "*frontage" required,* which ostensibly fall into categories of flood walls, sea walls, and earth embankments. This causes design problems, because the loading and ground conditions are always different and variable due to site-specific planning constraints. The interviewees had difficulty in differentiating between offsite construction and prefabrication with standardisation. Offsite and prefabrication "*refer to that part of the construction process that is carried out away from the building site*". On the other hand standardisation refers to "*extensive use of components, methods or processes in which there is regularity or repetition*" (Gibb and Pendlebury, 2006). Offsite units, predominantly concrete derivatives, are in use but the disorganised supply sector means that the design and construction teams face repeated challenges, causing lack of efficiency. Concluding, the client drive need for "*improved best practice"* formulates a fertile environment for offsite implementation in this sub-sector.

Discussion

The segmentation of the construction industry may initially appear to be a barrier for innovative construction. This applies especially for offsite because it focuses on engineering solutions. Nevertheless, this fragmentation enables concentration on the needs of the specific market sectors. The appreciation and usage of offsite varies greatly within sub-sectors. Offsite construction is not considered an innovation in the Maritime, Bridges and Tunneling sub-sectors. Other sectors have only recently started considering offsite solutions and methods. The continued advancement of offsite within particular sub-sectors depends on a series of factors including geography, geomorphology, local perception of risk, technological capacities, material and labour costs, procurement systems, etc. Therefore, the needs and requirements to realize offsite are different for each sub-sector depending on its level of 'offsite maturity'.

The two sub-sectors that this case study revealed with greatest potential for further research were Bridges and Water and Environment Management. Bridges, a more mature sector for offsite, have developed techniques because of the inherent nature of the bridge projects, many of which incorporate repetitive forms or sections. Nevertheless, the supply chain is not clearly defined and therefore the options considered often depend upon the individual designer or team's experience regarding offsite. This often causes duplication of innovative efforts which can sometimes lead to "*reinventing the wheel*". Therefore, small, one or two span road and rail, bridges were deemed ideal for standardization and offsite fabrication. The characteristics of such solutions are ideal for international knowledge sharing offsite technology. Markets such as Ireland and the UK are broadly geographically, technologically and ideologically similar. The Irish precast concrete market has flourished during the past decade producing innovative solutions which are widely applicable to the UK bridge market.

Water and Environmental Management is still an emerging sub-sector for offsite development. Recent requests for flood defence systems combined with government pressure for minimizing construction costs have forced the sector to look for more innovative solutions. As the sub-sector has no underlying historical offsite development, the supply chain is free to move across other sub-sectors in a quest to develop products and services to best cater for the clients' needs. Standardised design in collaboration with 'ex-situ' (on site but not in position) fabrication will help minimize cost and reduce disturbances.

Conclusion

The research undertaken focuses solely on one major UK design consultancy and although interesting conclusions are drawn these should not be generalized because they may not apply to all firms in the construction sector. Nevertheless, the data collection strategy employed could be applied to other firms and by comparing findings, new conclusions may occur. Furthermore, additional research should investigate how, in the current economic climate, internally driven innovation or client driven innovation is most appropriate to the realization of offsite construction in civil engineering and infrastructure. With increasingly tight profit margins, firms are becoming cautious of where research funds are being allocated. It is understandable that, to sustain their competitive edge, innovation is deemed to be crucial. Additional research is needed to further understand how firms prioritise internal needs for innovation in comparison with direct client requests and how this potentially could affect the future of the construction and infrastructure sector.

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