Realising offsite construction in the civil engineering and infrastructure sector

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Realising Offsite Construction in the Civil Engineering and Infrastructure Sector

Vasileios K. Vernikos
REALISING OFFSITE CONSTRUCTION IN THE CIVIL ENGINEERING AND INFRASTRUCTURE SECTOR

By
Vasileios K. Vernikos

A dissertation thesis submitted in partial fulfilment of the requirements for the award of the degree Doctor of Engineering (EngD), at Loughborough University

September 2015

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Firstly, I would like to thank my parents (Anastasia-Sissy Gika and Konstantinos Vernikos) immensely for supporting me throughout my life and enabling me to reach this point. My gratitude to my mother is endless, I would have never even considered an endeavour of this magnitude without her encouragement and I would have never reached the end without her continuous support and inspiration.

I would like to thank all my supervisors (Prof. Tim Broyd, Prof. Alistair Gibb, Dr. Chris Goodier and Prof. Peter Robery) and particularly Chris for his guidance and excellent supervision, through whom I improved myself as a researcher but more importantly as a person.

I would like to extend my gratitude to all the family and friends (Gregorio, Colin, Ilias, Adam) who have been close to me and especially Megan, who has been extremely patient with me during this difficult period.

This thesis was a true team effort. Thank you all so much, I am so very grateful indeed.
Vasileios
ABSTRACT

Offsite construction solutions have gained significant prominence over recent years. Much of the interest however, has been focussed on the building sector, in particular housing. The Civil Engineering and Infrastructure sector (CE&I) has comparatively seen little growth in this aspect. Specific exemplars for some high-profile projects, such as the Heathrow Airport control tower, do exist, but there have been far less applications of the new and emerging technologies and approaches that have been influential in the building sector recently. In addition, Offsite itself is not a well-defined supply sector, but rather a conglomeration of various, largely material or technology-based supply networks. This makes it difficult to realise new opportunities, especially in different sectors of the construction industry.

This thesis is the culmination of a four-year Engineering Doctorate (EngD) research programme investigating the components that affect the realisation of offsite in the CE&I sector. It commences with an introduction to the research and its aims and objectives, and moves on to present the methodological considerations. During the four Work Packages (WP) conducted, a total of 78 individuals participated and contributed to workshop and interviews, together with an extensive critical review of literature. All primary and secondary data was examined with appropriate methods, such as a comparative case study and an emergent thematic analysis, upon which a series of conclusions and subsequently recommendations were drawn.

The findings clearly identify that CE&I is more risk averse, and defines offsite differently, to the building sector. Each CE&I sub-sector has specific drivers and barriers to offsite, and due to the relative longevity of CE&I projects (both procurement, design, and construction) makes it difficult to benchmark and quantify offsite and its benefits. Large programmes of works rather than small projects are key to realising offsite as they provide confidence to the supply chain of long term investment. In addition, clients are pivotal for driving offsite as they can influence the industry’s focus; nevertheless, investment cycles in infrastructure clients hinders offsite realisation. For holistic offsite implementation organisation need to have a top-down strategy. Therefore offsite requirements should be embedded within the project delivery governance processes. Its realisation is linked directly to recruitment, training and research and development plans.

Building information modelling (BIM) now plays a key part in offsite realisation in CE&I as from 2016 it will be compulsory for all centrally-funded government works. BIM however, does not directly increase the offsite implementation, but it can help enable offsite due to the ability to define the design earlier in the project lifecycle. In addition, BIM encourages the use of software that can help identify the repetition of components, therefore increasing the potential for economies to scale. Finally, with the use of such software, delivery teams can simulate the construction sequence and therefore further help to enable offsite by reducing logistical challenges.

KEY WORDS

Offsite, Innovation, Building Information Modelling, Civil Engineering & Infrastructure
PREFACE

The research presented within this thesis commenced in 2010 and was completed in 2015 providing it has fulfilled the requirements of the Engineering Doctorate (EngD) of Loughborough’s University, Centre for Innovative and Collaborative Engineering (CICE). The research has been conducted within an industrial context and was sponsored by the global programme management and engineering consultancy, CH2M.

The EngD is assessed on the basis of a discourse (i.e. thesis) supported by a minimum of three and a maximum of five peer-reviewed publications. Presented within the Appendix section of this thesis are five papers, of which four are peer-reviewed conference papers and one peer-reviewed journal paper, all of which have been authored by the candidate.

The main body of the text provides an in-depth overview of all the work, the method employed, the findings and their implications. Specific details are explained within the publications included in the Appendix sections. Each of the papers is duly referenced within the thesis by a paper number (i.e. Paper 1). The papers are an integral part of the thesis and should be read in conjunction with it.
# ACRONYMS / ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AEC</td>
<td>Architecture Engineering and Construction</td>
</tr>
<tr>
<td>AIRTO</td>
<td>Association of Innovation, Research and Technology</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Modelling</td>
</tr>
<tr>
<td>BIMM</td>
<td>Building Information Modelling and Management</td>
</tr>
<tr>
<td>BIS</td>
<td>Department for Business, Innovation &amp; Skills</td>
</tr>
<tr>
<td>bn</td>
<td>billion</td>
</tr>
<tr>
<td>BS</td>
<td>British Standards</td>
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<tr>
<td>BSRIA</td>
<td>Building Services Research and Information Association</td>
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<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CE&amp;I</td>
<td>Civil Engineering and Infrastructure</td>
</tr>
<tr>
<td>CICE</td>
<td>Centre for Innovation and Collaborative Engineering</td>
</tr>
<tr>
<td>CIOB</td>
<td>Chartered Institute of Building</td>
</tr>
<tr>
<td>CIRIA</td>
<td>Construction Industry Research and Innovation Association</td>
</tr>
<tr>
<td>CTS</td>
<td>Council for Science and Technology</td>
</tr>
<tr>
<td>DfMA</td>
<td>Design for Manufacture and Assembly</td>
</tr>
<tr>
<td>DPoW</td>
<td>Digital Plan of Works</td>
</tr>
<tr>
<td>DQI</td>
<td>Design Quality Indicators</td>
</tr>
<tr>
<td>DTI</td>
<td>Department for Trade and Industry</td>
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<tr>
<td>EngD</td>
<td>Engineering Doctorate</td>
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<tr>
<td>EPSRC</td>
<td>engineering and Physical Sciences Research Council</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
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<tr>
<td>HM</td>
<td>Her Majesty</td>
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<tr>
<td>HMSO</td>
<td>Her Majesty’s Stationary Office</td>
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<tr>
<td>ICE</td>
<td>Institution of Civil Engineers</td>
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<tr>
<td>IFCs</td>
<td>Industry Foundation Classes</td>
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<tr>
<td>IMechE</td>
<td>Institution of Mechanical Engineers</td>
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<tr>
<td>IMI</td>
<td>Innovative Manufacturing Initiative</td>
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<tr>
<td>Inc.</td>
<td>Incorporated</td>
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<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
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<tr>
<td>IStructE</td>
<td>Institution of Structural Engineers</td>
</tr>
<tr>
<td>ITT</td>
<td>Invitation to tender</td>
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</table>
JIT  Just-in-time Management
KPI  Key Performance Indicators
Ltd  Limited
MCNS Meeting Clients Needs through Standardisation
Met  Meteorological Office
MMC  Modern Methods of Construction
MoJ  Ministry of Justice
MSc  Masters of Science
OCS  Offsite Construction and Standardisation
OSS  Offsite
PAS  Publicly Available Specifications
prOSPa  Promotion of Offsite Standardisation Prefabrication applications
RE  Research Engineer
R&D  Research and Development
RIBA  Royal Institution of British Architects
S&P  Standardisation and Prefabrication
SB  Sustainable Building
SBE  Sustainable Built Environment
SCI  Steel Construction Institute
TRADA  Timber Research and Development Association
TQM  Total Quality Management
TSB  Technology Strategy Board
TV  television
UK  United Kingdom
W&EM  Water and Environmental Management
WP  Work Package
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PAPER 2 (SEE APPENDIX B)

PAPER 3 (SEE APPENDIX C)

PAPER 4 (SEE APPENDIX D)

PAPER 5 (SEE APPENDIX E)
1 BACKGROUND TO THE RESEARCH

This chapter provides a general introduction to the subject of offsite construction and the overall research scope within the sponsoring firm and the construction industry. It also highlights the novelty and need for such a project.

1.1 THE GENERAL SUBJECT DOMAIN

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. 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 challenge construction efficiency.

 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 industry” (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 the fact that most of these initiatives aim 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. Methods from other industries were “made” generically relevant via theorising their fundamental principles and were then introduced for adoption in the civil engineering sector (Brensen and Maeshall, 2001).

1.1.1 THE UK OFFSITE MARKET

Various attempts have been made to quantify the UK offsite market (Goodier and Gibb, 2005; Goodier and Gibb, 2007), and most recently by Taylor (2010). The size of the UK “offsite fabrication” market was estimated to be worth £800.9m in 2002 (Samuelsson et al., 2003), which is 1.7% of new construction (£47.137bn in 2002). Goodier and Gibb (2007) estimated the total value of the offsite market in the UK to be £2.2bn in 2004, with the total value of the UK construction sector being £106.8bn. The proportion of the UK offsite market was
therefore 2.1% and was predicted to reach approximately £4bn by 2009. Buildoffsite predicted a market of £6bn by 2009 (Goodier and Gibb, 2007). Taylor (2010) obtained financial accounts for 245 companies operating within the UK offsite sector. From the market's turnovers and profits, he estimated that the value of the offsite would contribute between 6% and 7% of construction output and the value predicted for 2013 was £4.8bn (Taylor, 2010). This 2013 prediction considered the recession of 2008-09 whereas Goodier and Gibb's (2007) did not. Nadim and Goulding (2010) explained that the majority of growth would be in new buildings rather than refurbishment work and that the UK was ready to “embrace offsite production”. At that time, two thirds of respondents felt the UK was ready for such an uptake. The figure below presents the findings and predictions for the offsite market with dominant research focus on the building sector. The values vary significantly due to the remit and scope of each analysis. What is defined as offsite also is inconsistent which also affect the metrics applied and therefore the findings of the studies.

![Figure 1-1 Offsite sector’s valuation attempts (Goodier and Gibbs, 2005; Mtech group, 2006; Taylor, 2010)](image)

**1.1.2 Research and Development in the UK Construction Industry**

R&D in the construction industry has frequently been debated (Hampson and Brandon, 2004). The amount of money spent on R&D in the UK construction industry is insufficient to lead to performance improvements (Dulaimi et al., 2002). Sir John Fairclough’s 2002 report concluded that a “modern, efficient, high quality construction industry” would benefit society. In order to achieve this, he recommended innovation driven by R&D activities (Fairclough, 2002; Kulatunga et al., 2007 and 2009). Macmillan (2002) also argued that R&D activities were important in improving the performance of UK construction. R&D has been credited with the ability to influence and encourage best practice within the industry (Barrett, 2007). As with any
exploratory activity however, there are risks attached to undertaking R&D activities (Van Rooij, 2008; Mitchell and Hamilton, 2007). Kulatunga et al. (2009) suggest that R&D activities may not always deliver obvious benefits or generate large profits, but there is a possibility that construction organisations could benefit in the long run by considering less obvious innovations and changes. They argue that effective management to minimise the risks of R&D was required in industry, as opposed to “rejecting R&D altogether”. The need for more R&D, innovation and offsite is discussed in the literature, however innovation is risky, and offsite requires investment in manufacturing. Hence, if a major contractor chooses to invest, aside from the technical difficulties, it is critical to methodically review the company's culture aiming to embrace offsite within its normal business processes.

1.2 THE INDUSTRIAL SPONSOR

The research was supported by CH2M, an American programme management and construction firm. Initially the sponsoring firm was Halcrow Group Ltd, a global multidisciplinary engineering consultancy. The firm has circa 8000 employees across 90 offices, with 28 offices in the UK. Current work includes water, transportation, maritime, environment, power and property projects. Its clients include government departments, public sector authorities and utilities, industrial and commercial companies, international funding agencies and financial institutions.

During 2011, the firm went through a complete restructuring of its management systems, targets and processes in collaboration with external experts. During 2012, the Halcrow Group Ltd was acquired by CH2M Hill. This triggered another re-structuring of Halcrow which included a significant reduction of employee numbers. This continuous transformation and instability created a sense of “change fatigue” which made the innovation targets and all research projects related to them appear to be more challenging. Finally, in 2014, the firm went through its latest re-organisation and rebranding process. The focus was redirected away from construction to solely programme, project management and engineering consulting and a new name was chosen, CH2M. Notwithstanding, the research has continued despite these changes and has had continuous support from the organisation throughout.

1.3 THE CONTEXT OF THE RESEARCH

In order to deliver tangible results within the four year research timeframe, the research scope had to be carefully defined. The initial research scope was defined by the industrial sponsor and was refined and finalised during the first year of the EngD.

The preliminary literature review demonstrated that, depending on the sector or supply chain, the term offsite can vary in meaning. However, as aforementioned, in this research, offsite was used as an enveloping term and incorporated terms, such as Design for Manufacture and Assembly (DfMA), offline, prefabrication, industrialisation etc. Therefore, the research did not solely focus on offsite construction but also on onsite ex-situ (construction of elements or systems on site but not in their final position) where work is typically done in field factories. Due to the type of scale of construction in infrastructure projects, the research case studies focused predominately on non-volumetric (segments that do not enclose usable space e.g. ‘flat-pack’ reinforced concrete waste water tanks), volumetric (segments that enclose usable space
e.g. fresh water pumping pods) and complete structures (finished or partly finished structures that are installed in their final position e.g. foot bridge in one piece) rather than on component subassemblies (Figure 1.2.). Furthermore, elements of standardisation and standardised solutions were investigated. The standardisations considered were not limited to the repetitive production of specific solutions but also to standardised designs, bespoke standardisation, standardised processes and protocols that influence the realisation of offsite construction. A significant part of the research focused on how offsite is influenced by current industry innovations. Building Information Modelling (BIM) will be made a requirement (Bew and Underwood, 2009) to all government funded projects in 2016 (Morrell, 2011). As the research focuses on infrastructure and the main infrastructure client is the government, BIM’s effects on the realisation offsite in infrastructure offers interesting opportunities for research. In general, the research has also considered how offsite was used and managed within the sponsoring firm. In addition, there was significant input to the research from all supply chain parties (consultants, contractors, etc.), professional bodies (CIRIA, BSRIA, etc.) and relevant government departments (BIS, etc.). Figure 1.3. demonstrates the scope of the research graphically. The shading of the elements (circles) demonstrates how dominant they were within the research scope.
Figure 1-2 Research Scope - the darker the shading of the area the more prominent it is in the research.
2 OVERARCHING AIM AND OBJECTIVES

This chapter puts into context all the subsequent chapters of the thesis highlighting the aim, objectives, justification and the organisational context of the research.

2.1 OVERARCHING AIM AND OBJECTIVES

2.1.1 Aim

The aim of this research was to investigate the scope, constituent components and application of offsite construction in the Civil Engineering and Infrastructure (CE&I) sector. This aim was fulfilled via the completion of the following research objectives.

2.1.2 Objectives

Objective 1 – What are the applications of offsite in the CE&I sector?
This review was part of the initial phase of the research, which established a greater understanding of the overall topic, current knowledge and practice. This was achieved (Figure 2-1) by:
• Reviewing the scope and limitations of offsite construction;
• Identifying from existing literature the drivers and barriers for the application of offsite.

Objective 2 – What are the applications of offsite in the sponsoring (consulting) firm, its partners and clients?
This evaluation focused on the application of offsite within the industry organisation, and has identified:
• The types of offsite solutions currently applied within CE&I, and in what sub-sectors;
• The sub-sectors that lead in offsite adoption, and what instigates their dominance;
• The specific sub-sectors or areas within CE&I where there is potential for increased use of offsite.

Objective 3 – How BIM as a compulsory requirement for CE&I projects will influence the realisation of offsite?
This analysis explored the way that offsite construction is affected by the promotion of other innovation initiatives (e.g. BIM) that are regarded by the industry as vital. This was achieved by:
• Analysing how BIM affects offsite construction; and vice-versa.
• Analysing, through both theoretical and industrial lenses potential additional benefits that the collective application of offsite and BIM may offer.
Offsite construction 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 (Gibb, 1999; Taylor 2010; Goulding et al, 2015). Offsite is nowadays employed in many large scale building projects varying from hotels and hospitals to prisons and student accommodation (Pan et al, 2008; Lawson et al, 2014). Certain aspects, such as precast concrete elements, have also been widely employed in the CE&I sector, whereas other applications have had little deployment.

A series of initiatives such as BIM and offsite are currently taking place in order to mobilise efficiencies the UK construction industry, with a governing aim to reduce project costs through improved resource and data management. The use of offsite construction methods along with standardisation have been deemed equally appropriate approaches for reducing costs and construction time, while increasing construction quality (Paper 2 - Vernikos et al, 2012a; DBIS, 2013). In order to explore and realise the opportunities of offsite, one has to investigate the nature, constituent components and application of such solutions and processes in the context of the CE&I sector as a whole. Despite the significant progress of the industry, within the research industrial sponsor a number of challenges persisted which reinforced the need for this research, including:

- Inconsistent approaches toward offsite solutions and processes, particularly from different sub-sectors of the firm.
- Inability to understand the nature of offsite and therefore how best to exploit existing capabilities.
- A large variety of offsite innovation initiatives, including Modularisation and Standardisation, but without an over-arching coordinated strategic theme.
- Inability to leverage innovation by aligning key strategic research and development themes, including offsite.
- A difficulty in understanding key clients’ perception towards innovative offsite solutions.

The EngD literature review also highlighted the necessity of this research, as presented in Chapters 4 and 5. In summary, the findings demonstrate that:

- Offsite research in the UK construction industry is primarily focused on the building and housing sectors.
• There is a shortage of research into offsite for CE&I, including investigating drivers and barriers, and how solutions developed could be implemented.
• Limited research has been conducted with regards to approval processes and risk perception of key governmental authorities which can influence drastically the realisations of offsite innovations.
• There is insufficient understanding of how client demands influence the realisation of offsite in the sector.
• Limited knowledge exists on how key industry initiatives affect the development and implementation of existing offsite solutions and the formation of new opportunities.

Further research was therefore required first, in order to identify what influences the realisation of offsite in CE&I and secondly, to build upon and expand the existing findings from existing limited academic and industry research. As demonstrated in the following sections the findings are not restricted solely to the research sponsoring organisation. Nevertheless, the sponsoring firm’s multidisciplinary structure, its global reach, and the size and type of projects undertaken makes it a prime example of a typical case within the broader engineering and construction consulting market. Therefore this research provides such organisations with a comprehensive analysis and understanding of offsite issues within the CE&I sector.

2.3 WORK PACKAGES

The research was divided into five distinct Work Packages (WPs), ensuring that all the objectives were addressed and that the research remained within scope. Each Work Package contributed to a specific objective.

Work Package 1 – Investigate the current stage of offsite

The first task facilitated an understanding of the basic principles and focussed on the scope of the research, satisfying the requirements of Objective 1. A review of the definition of ‘civil engineering and infrastructure’ was undertaken to apply boundaries to the research topic. In addition, a second literature review focussed on offsite and other terminology of the subject, including: Prefabrication, Modularisation, Modern Methods of Construction, Design for Manufacturing, and Preassembly. The research demonstrated a gap in literature on offsite with regards to the CE&I sector. The majority of the literature focused on the building sector, its barriers and constraints, past and current strategies. A comparative case study was undertaken to understand leading barriers and drivers for offsite, specifically in CE&I sector. The findings of this research initiative identified approval process and the contractual frameworks to be key in the realisation of offsite. The outputs of the aforementioned comparative case study research were Papers 1 and 5.

Work Package 2 – Assess the application of offsite in the supply chain

The second WP gathered and analysed data from CE&I delivery firms such as consultants and contractors. Initially, the industrial sponsor’s approach on offsite was reviewed and specific attention was given into researching which sub-sectors, within CE&I, had the greatest potential to realise offsite. As an engineering consultant the industrial sponsor was used as a case study organisation. Each sub-sector department was approached individually. Research was undertaken to identify the drivers, barriers, advantages, disadvantages and solutions used for each department. In addition, a thorough investigation into the strategies of construction firms
was undertaken and one contractor was chosen as a case study. The outputs of this WP were Papers 2 and 3.

**Work Package 3 - Assess the application of offsite in client organisations**

Client organisations which procure, manage and operate infrastructure assets were also investigated. Initially their perception of risk and offsite innovation was researched. Consequently, through the analysis of the data from WP2, the Water and Environmental Management (W&EM) sub-sector was identified as having the most potential for realising offsite. This finding instigated further research aiming to gather and analyse data in order to establish the sub-sector’s clients’ views on offsite. The outputs of this WP were Papers 1 and 4.

**Work Package 4 - Investigate the relationship between Offsite and BIM**

As the industry innovation initiatives has changed, their effects on the realisation of offsite needed to be examined. A further extensive literature review was conducted to identify and understand key government driven industry innovation initiatives, such as BIM. The conclusion identified BIM as a primary focus for the government. A grounded theory approach was used to investigate the way BIM affects the realisation of offsite. The output of this WP is included in Paper 5.

**Work Package 5 – Verify all research findings**

For the concluding element of the research, a synthesis of all the findings and evidence-based conclusions was summarised. In addition to existing findings, qualitative analysis was conducted aiming to produce a state-of-the-art report on offsite in the CE&I sector. The implications of this synopsis were to be considered by the sponsoring firm, the industry and the academic community. Following this, recommendations were made for the future development of offsite within the sector. The output of this WP is embedded throughout the thesis, predominantly in Chapter 5, and will be the focus of a future journal paper.

<table>
<thead>
<tr>
<th>Work Packages</th>
<th>Aim</th>
<th>Publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP1</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WP2</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WP3</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>WP4</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>WP5</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
2.4 LIST OF PUBLICATIONS

A number of journal and conference papers were published to disseminate the findings and knowledge gained through the research project as tabulated below.

<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>Type</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper 1</td>
<td>Realising offsite construction and standardisation within a leading UK Infrastructure consultancy</td>
<td>Conference</td>
<td>Published</td>
</tr>
<tr>
<td>Paper 2</td>
<td>Implementing an offsite construction strategy: a UK Contracting organisation case study</td>
<td>Conference</td>
<td>Published</td>
</tr>
<tr>
<td>Paper 3</td>
<td>Offsite innovation in UK Infrastructure: the role of the approvals process in box jacking projects</td>
<td>Conference</td>
<td>Published</td>
</tr>
<tr>
<td>Paper 4</td>
<td>Analysing the need for standardisation and modularisation in the UK Water and Environmental management sectors</td>
<td>Conference</td>
<td>Published</td>
</tr>
<tr>
<td>Paper 5</td>
<td>Investigation into how Building Information Modelling affects the realisation of offsite Construction</td>
<td>Journal</td>
<td>Published</td>
</tr>
</tbody>
</table>

2.5 NOVELTY OF THE RESEARCH

The research provides a unique insight into the utilisation, role and management of offsite within major CE&I client, consulting and construction firms. The author had the opportunity through his cross-region, cross-sector position within the sponsoring organisation to assess and analyse the topic, accessing unique views and opinions of key stakeholders, both internally and throughout the supply chain. This enabled the author to examine and subsequently evaluate real industry data, hence offering tangible conclusions.

More specifically, it is anticipated that the research will make the following contributions to the field:

- An analysis of the way risk for innovative offsite solutions is perceived by key approval bodies.
- An analysis of the drivers and barriers for each individual sub-sector of CE&I.
- A review of client organisations’ needs for offsite, focusing on the water and environmental management sub-sectors.
• An analysis of the effects on offsite implementation of key innovation themes governing the industry.

A key area of the thesis covers the relationship between BIM and Offsite. Modernising the UK construction industry has been on the agenda of the UK government many times (Wolstenholme, 2009) and various attempts and initiatives have been documented, addressing different aspects of it (Simon, 1944, Emmerson, 1962, Banwell, 1964, Latham, 1994, Egan, 1998). Recent initiatives – such as BIM, lean construction and offsite – aim to reduce costs through improved resources and enhanced data management (Vernikos et al, 2011) with BIM becoming increasingly applied within the UK construction industry in recent years. BIM implementation is occurring via a ‘push–pull’ process and BIM is slowly becoming embedded in various forms and methods in many current construction projects (National BIM Report, 2013). The UK government wants to achieve a total of 20% savings of construction costs and aims to implement BIM in all government construction procurement contracts by 2016 (Morrell, 2011) hoping to contribute to the savings target. Many would consider this target to be a real challenge, solely through the implementation of a single innovative initiative, in such a short time.

The compulsory nature of BIM and its impact on the UK infrastructure would undoubtedly affect the realisation of offsite. Additionally, the industry and the sponsoring firm invested heavily in its adoption which would again affect their focus on offsite. Therefore, BIM was seen a factor the research should have analysed and evaluated its impact on offsite (Appendix K).

2.6 STRUCTURE OF THE THESIS

This thesis is organised into five chapters:

Chapter 1 presents a high level introduction of the topic, the research sponsor and the scope of the thesis.

Chapter 2 presents the aim, the objectives and how they are linked with the work packages and the publications.

Chapter 3 explains the methodology adopted in carrying out the research. The different approaches available are also discussed and this chapter concludes with the specific methodology and data collecting method adopted.

Chapter 4 provides a detailed description of the results of the research. The way offsite affects the construction industry is categorised in four distinct groups, consultants, contractors, clients and industry support organisations, as well as academia.

Chapter 5 discusses the key findings of the research and includes the impact of the research on the wider industry and more specifically on the industrial sponsor. It also critiques the research and presents suggestions of areas for further investigation.

In the appendices one can find the papers chosen to accompany the thesis and other useful information.
3 ADOPTED RESEARCH METHODOLOGY

3.1 INTRODUCTION

A thorough analysis of existing research perspectives and research methods took place for the thesis. The purpose of this chapter is to present the methodological parameters that influenced the research, to outline the chosen methodology and data collection methods, and to explain the rationale behind the chosen approach.

3.2 METHODOLOGICAL CONSIDERATIONS

For a doctoral thesis to be considered as robust, a rigorous research process has to have been followed. The procedures and practices employed for such an investigation are defined in the research methodology (Clark, 2000). The research methodology has to be scientifically acceptable, and be appropriately deemed for collecting and analysing information, aiming to define principles and generate new knowledge regarding a specific phenomenon (Naoum, 2006). The methodology has to be structured in a workable, reliable, unbiased and objective way. It is important to highlight that the methodology is governed by a series of assumptions and the interpretation of its outcomes (Crotty, 2003; Easterby-Smith et al, 2002).

3.2.1 EPISTEMOLOGY

Epistemology refers to the theory of knowledge and questions what knowledge is and how it can be acquired (Easterby-Smith et al, 2002). Creswell (1994) presents four different approaches to epistemology and the main elements of each approach (Table 3.1). Pragmatism was adopted in this research as it is not committed to any specific system of philosophy and reality. Pragmatists do not perceive the phenomenon as an absolute unity and look into many approaches to gather and review data (Creswell, 2009). This approach is focused on “actions situations instead of antecedent conditions” and is concerned with application and problem solving (Creswell, 2009).

Table 3-1 Four differences Epistemologies (Creswell, 2009)

<table>
<thead>
<tr>
<th>Positivism</th>
<th>Constructivism &amp; Interpretivism</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Determination</td>
<td>-Understanding</td>
</tr>
<tr>
<td>-Reductionism</td>
<td>-Multiple participant meanings</td>
</tr>
<tr>
<td>-Empirical observation &amp; measurement</td>
<td>-Social &amp; historical construction</td>
</tr>
<tr>
<td>-Theory verification</td>
<td>-Theory generation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advocacy/Participatory</th>
<th>Pragmatism</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Political</td>
<td>-Consequences of actions</td>
</tr>
<tr>
<td>-Empowerment issue-orientated</td>
<td>-Problem-centred</td>
</tr>
<tr>
<td>-Collaborative</td>
<td>-Pluralistic</td>
</tr>
<tr>
<td>-Change-oriented</td>
<td>-Real-word practice oriented</td>
</tr>
</tbody>
</table>
3.2.2 **Ontology**

Ontology is part of the assumptions the researcher has to define before embarking on the research journey. These assumptions are made about the nature of reality (Easterby-Smith et al., 2002), and can be measured on a continuum with one side of the spectrum being the ‘realist’ (i.e. objectivist) to the other side, which is a ‘relativist’ (i.e. subjectivist) perspective (Coghlan & Brannick, 2005). The realist view perceives that the phenomenon is tangible, “fixed” and external, and occurs independently of one’s cognition (Coghlan & Brannick, 2005). On the other hand, the relativist view perceives that a plethora of realities may exist as subjective constructions of the mind (Easterby-Smith et al., 2002).

The ontology used in this research is from the perspective of critical realism. This assumption is a conscious compromise between the two extreme aforementioned positions. This approach believes that there is a reality which exists independently of our experience, but acknowledges that reality is shaped by actions and dialogue (Coghlan & Brannick, 2005; Easterby-Smith et al., 2002).

3.2.3 **Paradigm**

According to Fellows and Lui (2005), the research paradigm is a theoretical framework which describes the way that individuals view and approach problems within a research project. Research can be positivist or interpretivist. Positivism is founded on the belief that there are certain fixed laws of causation and therefore only clearly observable phenomena are considered for choosing research methods and analysing the data in hand (Woods and Trexler, 2001). Interpretivism acknowledges that reality is context-dependant and thus it is expected that the data collected and analysed will be influenced by that fact (Fellows and Lui, 2005; Kumar, 2005). The paradigm in this research takes an interpretivist perspective.

3.2.4 **Research Objective**

The objectives of every research project will either be exploratory, correlational, descriptive or explanatory (Kumar, 2005). The research objective type adopted by this research project is *explanatory* as it investigates specific phenomena and aims to explore how and why such phenomena occur.

3.2.5 **Research Type**

Research can be either pure or applied depending on its application (Kumar, 2005). Pure research is abstract and involves the development, analysis and validation of hypotheses that may not be applicable to a practical situation. In contrast, applied research is practical and directly relates to a pragmatic problem. This engineering doctorate research is applied.

3.2.6 **Mode of Enquiry**

There are two main governing modes of enquiry, the qualitative and the quantitative (Naoum, 2006, Creswell, 1994); a more detailed presentation of the two approaches is shown on Table 3.2. The quantitative approach focuses predominately on factual information that is quantifiable and can be validated through testing and measuring it. This includes numerical data that can be collected and analysed through statistical variations (Blaxter et al., 2003). Conversely, the qualitative approach is a way to analyse and understand the world of human experience (Creswell, 2007). In qualitative research data is collected in a natural setting and analysed inductively in order to identify patterns or themes. This approach best suits a topic where the
research problems need to be explored, where there is complexity, and a detailed understanding is required (Creswell, 2007).

Table 3-2 The differences between quantitative and qualitative research (Kumar, 2005)

<table>
<thead>
<tr>
<th>Difference with respect to</th>
<th>Quantitative Research</th>
<th>Qualitative Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underpinning philosophy</td>
<td>Rationalist</td>
<td>Empiricist</td>
</tr>
<tr>
<td>Approach to inquiry</td>
<td>Structured/predetermined methodology</td>
<td>Unstructured/semi-structured or open methodology</td>
</tr>
<tr>
<td>Main purpose of investigation</td>
<td>To quantify the extent of variation in a phenomenon or situation</td>
<td>To describe variations in a phenomenon or situation</td>
</tr>
<tr>
<td>Measurement of variables</td>
<td>Emphasis on some form of either measurement or classification of variables</td>
<td>Emphasis on description of variables</td>
</tr>
<tr>
<td>Sample size</td>
<td>Emphasis on greater sample size</td>
<td>Fewer Cases</td>
</tr>
<tr>
<td>Focus of Inquiry</td>
<td>Narrows focus in terms of extent of inquiry, but assembles required information from a greater number of respondents</td>
<td>Covers multiple issues but assembles required information from fewer respondents</td>
</tr>
<tr>
<td>Dominant research value</td>
<td>Reliability and objectivity</td>
<td>Authenticity but does not claim to be value-free</td>
</tr>
<tr>
<td>Dominant research topic</td>
<td>Explains prevalence, incidence, extent, discovers regularities and formulates theories</td>
<td>Explores experiences, meanings and perceptions</td>
</tr>
<tr>
<td>Analysis of data</td>
<td>Subjects variables to frequency distributions, cross tabulations or other statistical procedures</td>
<td>Subjects responses or observation data to identification of themes and describes these</td>
</tr>
<tr>
<td>Communication of findings</td>
<td>Organisation more analytical in nature, drawing inferences and conclusions and testing magnitude and strength of a relationship</td>
<td>Organisation more narrative in nature</td>
</tr>
</tbody>
</table>

3.2.7 RESEARCH APPROACH

The research approaches below were considered for this research, however not all were employed. The same research approaches can be used across different philosophical perspectives (Fellow and Lius, 2005). Nevertheless, the decision for choosing a research approach should be made on the basis of what is the most suitable for the type of data to be collected.

3.2.7.1 Case Study Approach

Due to the nature of the research, a great deal of data was collected through analysing and understanding the offsite projects currently underway or completed. Examples include Paper 1 (Appendix A), where the sponsoring firm was used as the focus of the case study. After an industry analysis in Paper 2 (Appendix B), the construction firm with the greatest offsite focus was used as the case study. Case studies have the advantage of focusing and exploring specific details of research that often other methods overlook (Denscombe, 2007). Albeit, when a researcher is attempting to draw generalised conclusions, one has to state the assumptions
considered in order to allow the case study conclusions to be transferable (Blaxter et al, 2003). The research projects were assessed as case studies (Yin, 2009) and the data was recorded and analysed accordingly. Figure 3-1 discusses the relationship between this research approach, the work packages and the papers published.

3.2.7.2 Grounded Theory

The creation of new knowledge involves a research approach that allows the researcher to assess the topic, and collect and analyse any data which is available (Glaser et al, 2007). This enables the appearance of underlying patterns (Glaser and Strauss, 1998). According to Glaser and Strauss (1967), classic grounded theory offers a holistic approach for conceptualising such underlying patterns. This research approach was employed during Work Package 3. The impetus for adopting grounded theory for the research approach, in contrast to continuing with the qualitative analysis, was due to a distinct need to develop a new theory regarding offsite in CE&I, instead of adopting existing theories for interpreting the data collected. Although qualitative analysis was sufficient for the Work Packages 1 and 2, the research was overwhelmed by data, definitions and descriptions when offsite was assessed in relation to BIM. Grounded theory was prominent on Paper 5 (Appendix E) where there was a need for avoiding data adjusting or steering towards previous theoretical frameworks. This approach prevented the contraction of the research scope by allowing the interviewees to focus on topics they considered governing and pertinent. Analysing and interpreting data using grounded theory required a flexible approach in order to identify emergent themes. According to Keller (2005), “the controversy between Glaser and Strauss boils down to the question of whether the researcher uses a well-defined 'coding paradigm' and always looks systematically for “causal conditions,” “phenomena/context, intervening conditions, action strategies” and “consequences” in the data, or whether theoretical codes are employed as they emerge in the same way as substantive codes emerge, but drawing on a huge fund of “coding families”.

3.2.7.3 Emergent Thematic Analysis

A thematic analysis (Guest, 2012; Fereday and Elimear, 2006) was used to analyse data retrieved through semi-structured interviews. The interviews were transcribed before the initial coding exercise. The data was then subtracted, refined and combined to create new codes. When data saturation occurred, the creation of the themes was conducted. This method was used to analyse the interview transcripts for Paper 5 (Appendix E). The transcripts were divided into sentences and were transferred from MS Word into MS Excel (Figure 3.1). Following this, each sentence was ranked according to its theme. Each interview was analysed on a separate worksheet, then all the sheets were merged and “pivoted” into a different file to create a thematic breakdown. The methodology section of the paper discusses in more detail the methodological process followed.
In recent years, a multi-method approach is being increasingly adopted by the research community as it offers multiple data for the same research problem that improves the quality of findings (Bryman, 2004). This is because, through the multi-method approach, limitations of some methods are mitigated by others. Each set of data being collected for a specific purpose and analysed accordingly provides the researcher with a data diversity that allows for a better perspective on the research problem (Bonoma, 1985). A mixed method approach is the most suitable for applied research as it is expected to produce tangible findings.

3.2.8 DATA COLLECTION METHODS

When collecting data, the researcher should consider the type of data required for the research. Data is divided in two main categories depending on its source. Primary data, or “raw data” can include information collected through interviews, observation, questionnaire, action research workshops, etc. Secondary data includes information that has been analysed or collected by others. Figures 3-2 and 3-3 demonstrate what primary and secondary data collection methods were adopted, linking them to the output from that process. Some examples include previous research publications, official statistics, online information, etc. Both primary and secondary data can be employed within a well-structured and rigorous research methodology. Not all the data collection methods described below were employed, but as they were considered in the research, they have to be included for completeness.
3.2.8.1 Interviews

Interviews can be structured, semi-structured or unstructured (Kumar, 2005; Naoum, 2006). Each interview method has its own merits and drawbacks. Structured interviews ask the same exact question to all the participants in the same way, limiting the participants’ interviews both in time and scope. In a semi-structured interview the researcher asks open-ended questions. The nature of the question defines the topic under investigation without limiting the interviewee. If the interviewee has difficulty understanding the question, it can be re-phrased. In an unstructured interview the researcher investigates specific topic with more flexibility as he has no specific questions for the interviewee (Hancock et al, 1998).

A research interview can be conducted face-to-face or via the telephone. Again, each method has its advantages and disadvantages. During a face-to-face interview the researcher can observe reactions, probe and clarify answers that may not be as clear. Nevertheless, such a method may prove costly, time consuming and contain interviewer bias and/or influence. The telephone interview is considerably faster and more cost effective, due to the lack of travel required. It also allows for a greater geographic reach as the interviewee may be abroad. The disadvantage is that, usually the length can be more limited and there may be a difficulty in discussing specific topics (Dawson, 2009).

During this research more than 40 face-to-face interviews were conducted. Each interview process is discussed in more detail within the methodology section of the appended papers. An in-depth literature review was conducted prior to the interviews, which supported the creation of the interview questions - an example can be found in Appendix J. All interviews were recorded and transcribed before analyses with the pre-identified process.

3.2.8.2 Workshops

Focus groups or workshops are employed when the researcher wants to discuss various issues with a group and capture their views on them (Bouma and Ling, 2004). Workshops are complex activities and need careful preparation. The conceptual framework of a workshop includes the group cohesion, the discussion process, group composition, research setting, the moderator and the group process factors (Fenn, 2001). Ensuring the correct balance of all workshop variables minimises the potential bias of the data captured. The group cohesion refers to the sense of closeness and common purpose. The discussion process ensures the group collaborates, and that its members contribute to the discussion uniformly without participants antagonising each other. The correct group composition is similar to the sampling method used in questionnaire research. It is critical that the focus group includes members who as a group can deliver a balanced option to the research topic raised (Fenn, 2001). The research setting is also important, as the workshop should be conducted in an environment appropriate for the research topic with material and equipment suitable for the purpose of the workshop. One of the key sections of the workshop process is the discussion. In this research, workshops were used to supplement data collected via interviews. Furthermore, the data presented to the group was analysed as the workshops were used for triangulation and the aim of the task was to understand if the findings aligned with the opinion of the group. The output from these workshops were 3 reports (Appendix F, Appendix G, Appendix H)
3.2.8.3 Questionnaires

A questionnaire is a list of questions issued to the participants using a variety of potential delivery methods. As the questionnaires are completed in the absence of the researcher, it is critical that the layout, structure and language are clear and concise, and ambiguity is avoided (Thomas, 1996). In comparison to other data collection methods the questionnaire is a relatively direct (and simple) way. Nevertheless, if the sampling method has not been clearly defined, it could create bias in the data collected, distorting the findings of the research (Fellow and Liu, 2003). This, coupled with a low number of respondents, can make this data collection tool impractical, or even worse, it can provide incorrect data and findings. The delivery method may be via telephone, mail or email. In If compared to the aforementioned data collection methods a questionnaire is less expensive and can also provide anonymity. A draft questionnaire, following Gillham (2008), was developed for WP5, considering all the parameters above. The questionnaire (Appendix L) was developed based on all the conclusions drawn from the 5 published papers and a final literature review. It was distributed to the triangulation workshop attendees prior to them taking place in order to inform the workshop facilitator on the areas of focus, understand the attendees’ perspective and create the appropriate material to discuss.

3.2.8.4 Observation

Action research or direct observation research is a technique that has several applications one of which is when data collected is of limited value or difficult to evaluate, according to Hancock et al, 1998. The accurate observation of the participants ensures the validity of the data. Nevertheless, one has to take into account the fact that the observes are aware of the research and therefore may act accordingly (e.g. be more thorough than usual) The principle of action research is the direct involvement of the researcher in the process under investigation aiming to identify, collect, develop and evaluate data which will assist him in answering the research question (Bryman, 2008). Action research has been used in cases where the researcher was actively involved in projects or tasks related to the sponsoring firm’s case load. In Paper 3 (Appendix C) observation research was used as it this provided a transparent environment and unlimited access to data.

3.2.9 TRIANGULATION

Triangulation can be used with both qualitative and quantitative data, irrespective of the way it was collected and analysed (Fellows and Liu, 2003; Shank, 2006). Triangulation is employed to add rigor to the research method employed by verifying the findings of the research. In addition, triangulation strengthens the research findings as it minimises deficiencies that other methods may have. This method allows any bias or weaknesses from the data collection or analysis to be identified and be included in the research conclusions (Silverman, 2004). The triangulation exercise undertaken during this research was via three workshops. During the workshops a total of 35 participants discussed the key conclusions of the research. The output of each workshop was a report summarising the process, participants, discussion points and conclusions (Appendix F, Appendix G, Appendix H). All work shop delegates were sent the reports to confirm accuracy of the findings.
3.3 METHODOLOGY DEVELOPMENT

Within the research field there are various approaches to methodology and although most researchers attempt to separate them and present them as a straightforward process, the reality is more complicated (Lewis, 1994). According to Glaser (1998) the decision on the approach should be based on the research “appeal, goal, cost, rigor, interpretation and usefulness”. Others (Stern, 1994, Annells, 1996) believe that the decision depends on the disciplinary expectations of the research question. Goulding (2003) argues that the choice of research approach should focus not only on the research but also on the person conducting the research and their style of work.

Secondary research focuses on studies that other researchers have conducted leading to books, articles, papers or even debates and discussions. In general, the engineering doctorate literature review is an ongoing process throughout the duration of the project. Regarding primary data collection methods, the data collected throughout the research was qualitative data. Throughout the doctorate a series of smaller research projects were conducted. The research methods or tools used for each publication are described in Figure 3.4. Each Work Package adopted a specific data collection method according to the requirements of the objective that was being addressed (Figure 3.3).
3.4 ETHICAL CONSIDERATIONS

Ensuring that research is conducted in an ethical manner is vital (Ritchie et al, 2013). In all interactions with interviewees or during focus groups everyone was informed of the purpose of the research and they were all given a brief description of the research project. They were informed that the process was going to be recorded and that they will remain anonymous and findings of this research may be published or presented in an academic context. The university’s procedures for ethical research were also followed (e.g. Ethics Form submitted – Appendix I).

3.5 SUMMARY

Figure 3-3 clearly presents how the aim, objectives, Work Packages, adopted methodology, and outputs are linked cohesively to produce the resultant doctoral thesis. The governing ontology was critical realism and the epistemological assumption was pragmatism. A variety of data collection and analysis research methods were adopted, involving a collaborative approach towards a process of problem solving, in order to identify the need for change that would embrace offsite in organizations and contribute to scientific knowledge within the CE&I industry. All the aforementioned considerations combine to strengthen the findings, and therefore the conclusions of this thesis are drawn confidently.
Figure 3-3 The way each of the sections relates to methodology, aims, objectives and output.
4 THE RESEARCH UNDERTAKEN AND RESULTS

This section reports on the research undertaken throughout the doctoral research and discusses results and findings. The results presented in this section have been published in the five papers included in the appendices. Each section commences with a short introduction briefly describing the source of the collected data before moving on to discuss the findings from the analysis.

4.1 INTRODUCTION

Significant research into offsite, throughout the past decades, had taken place (Taylor, 2010) with several papers published using a plethora of terms (Figure 4.1). Currently due to several new terms predominantly driven by the industry (e.g. Design for manufacture and assemble, factory thinking construction, industrialised infrastructure, productisation design) it was proven not feasible to tabulate all the terms. A part of these publications focuses on the drivers and barriers to offsite (Nadim and Goulding, 2010; McKay, 2010; Soetanto et al., 2006; Blismas et al., 2006; Gibb, 2001; Goodier and Gibb, 2005a; Goodier and Gibb, 2007). Attempts to establish similarities in approach between construction and manufacturing companies have been made, and it has commonly been suggested that offsite should utilise manufacturing techniques similar to those used in automotive manufacturing (Egan, 1998; Crane et al., 2002; Constructing Excellence, 2009). The automotive industry is often cited as championing standardisation and mass production (Pan and Arif, 2011). Increased standardisation of components in buildings can result in fewer defects, higher quality and a more reliable rate of production depending on less fluctuation in construction programmes of projects (Egan, 1998; Gibb and Isack, 2003).

![Figure 4-1 Offsite publications from 1968 until 2009 (Taylor, 2010).](image)

Currently, the UK Government is looking into offsite as an option for cheaper, more affordable housing (Miles and Whitehouse, 2013). There is also significant knowledge regarding the principles behind manufacturing and offsite (Gann, 1996; Pan and Arif, 2011; Gann, 2010). 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). The construction industry as a whole has had several government reports tackling inefficiency through various initiatives; 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).

Although most of these initiatives do not aim to focus on a specific sector, the majority of industry applications and academic research projects have been aimed at the building sector (Pan et al., 2007). As part of this research, the findings of the literature during WP1 regarding advantages and disadvantages were tested with a subject matter expert from the client and supply chain organisations at the workshops as part of WP5.

4.1.1 Benefits

The most important benefit of offsite construction identified for the infrastructure sector was quality. The majority of research participants claimed that by using offsite, there was not only greater consistency by minimising variability of specifications and the overall build form but also improved quality on the whole by getting it right the first time. Safety was also one of the most acknowledged benefits, especially amongst contractors and clients. Participants emphasised that by having fewer staff on-site, there is less potential for accidents. The assembly process was discussed, and activities such as controlled lift were seen as safer since most construction activities take place in a safer environment away from the construction site. Nevertheless, recent data from the Health and Safety Executive (HSE) discussed by Buildoffsite (Krug and Miles, 2013) shows that the injury rates for general manufacturing and construction sectors have converged in recent years, with a slight divergence only in fatal injuries. There is a clear discrepancy in the industry’s perception of statistical data. The most debated benefits were associated with the construction schedule (i.e., programme) and how offsite affects it, despite it being deemed less important than quality and safety. It was also agreed that offsite provides greater predictability of schedule, and despite longer planning time, there is faster on-site delivery and assembly.

An additional point linked to the programme was the reduction of disruption on-site due to better management of vehicle movements and site-space requirements. Furthermore, cost-related benefits were seen as of equal importance to the programme. The higher cost certainty and cost effectiveness through standardisation of offsite solutions were closely linked to the increase of value of a project. Offsite systems were seen as more efficient in reducing overall costs, although it was argued that these reductions often appear to be offset by increased transportation costs. Addressing the industry’s skill shortage through offsite construction was ranked amongst the most important, but it was not mentioned by the participants. This benefit emerged when the group reviewed the advantages identified by the literature. Sustainability was also discussed but not seen as a benefit of critical importance. Participants believed that offsite construction results in reductions of energy consumption, waste and noise.
4.1.2 Risks

Participants discussed current offsite risks, and procurement was identified as most important. The fragmentation of contracts, coupled with over-controlled procurements, often makes offsite a nonviable business case. Certainty of project pipeline to generate internal rate of return (IRR) on facilities was seen as critical. It was underlined that there is a need for large-scale programmes to ensure that the supply chain maintains their offsite capabilities profitable. Nevertheless, examples were discussed where large clients’ procurement intent and their control of financial exposure to single Tier 2 suppliers have been seen to act as a barrier to implementing specific offsite solutions as procurement is seen to reduce competitiveness. Procurement is the main limitation to achieving economies of scale with offsite solutions; consequently, offsite usually appears to be more expensive.

The second risk to offsite was thought to be the process. Participants acknowledged that offsite is not always considered at the early stages of a project. Therefore, a poor process and insufficient understanding of the importance of the process hinders its adoption. Retrospective application of such solutions is often suboptimal. Participants closely linked the process risk with the design risk. It was echoed by all that design has to be well developed and locked at an early stage. Some participants argued that standardised designs should be used more at the early stages, but others thought that there are insufficient design developments (e.g. limited offsite design options) which result in the over prescription of solutions (Paper 4 - Vernikos et al., 2013b).

Lack of investment and overall initial capital cost were seen as a significant blocker to offsite, especially from client organisations, as the capital expenditure (capex) risk was perceived to be too great. Equally, important to lack of investment was the perceived inflexibility of the design. Offsite was seen as rigid and inflexible in relation to late changes - “late changes are often due to failures within the project processes”, which increases risks. At that point, some participants argued that infrastructure is a prototype industry, but it should not remain that way.

The overall perception of offsite through the wider construction industry was heavily debated; the discussion expanded and covered topics such as investment on research and the general adoption of innovation. Participants agreed that, due to a legacy of poor results and with offsite seen as “blunt and boring”, the construction industry is reluctant to adopt it. This negative
perception was seen by the group as an overall lack of awareness. Moreover, existing technical standards were also seen as a blocker to offsite. The participants believed that they are inflexible and outdated, as some were developed 30 years ago. The correlation between output specifications and the performance specifications should be reviewed, as prescriptive requirement stifles the adoption of offsite thinking.

4.2 OFFSITE IN CONSULTING ORGANISATIONS

The increase of competitiveness is of critical importance for all consulting firms, independently of the economic health of the construction industry. To achieve the desired level of competitiveness, consultants have shown interest in more innovative construction solutions, renewing construction practices, policies and processes; reviewing advantages and disadvantages, aiming at cost reduction while maintaining healthy margins (Paper 2 - Vernikos et al, 2012a). This section focuses on a case study of a leading UK infrastructure consultancy, which is part of WP2, and the findings are discussed extensively in Paper 2.

4.2.1 METHOD

A comprehensive analysis of the innovation trends which influence the evolution of the construction industry based on a literature review was undertaken. This was followed by a concise review of offsite application in civil engineering subsectors (i.e., maritime, bridges, etc.). The data collection is based on this case study, where the sponsoring firm has been used as an example. The Eisenhardt (1986) approach has been employed for the research design, which is to promote the dynamic research potential of offsite innovation in an engineering consultancy by making use of multiple analysis levels within a single study. Literature review, a brief survey, focus groups and interviews have also been incorporated as research tools. An initial scoping pilot study was conducted so that the most relevant staff would be identified before starting the second stage of the data collection. The questionnaires were forwarded through e-mail. A pro forma interview question was used to maintain consistency, as the interviews were semi-structured. Six interviews followed, which aimed to identify the perception of offsite and the potential development opportunities for innovation in each sub-sector of the case study firm. The interviews were followed by two focus group discussions, which completed the analysis and verified the findings.

4.2.2 FINDINGS

4.2.2.1 MARITIME

In the maritime subsector the offsite market size is estimated to be around 30-40% of all works, as per Vernikos et al (2012). The speed of construction and a more environmentally friendly assembly have been seen as the most important benefits of offsite solutions. Data has indicated that contractors often drive the design with their knowledge from past experiences and the equipment they got either in their possession or in proximity to the project. There are issues related to the environment, quality control, health and safety and reduction of commercial risk which have clearly been identified as advantages of precast concrete solutions which are inherently offsite. One of the fundamental drivers for using precast concrete in coastal projects is that the majority are design and build; therefore the project team can fully exploit the potential quality and speed of construction benefits of precast concrete. In the case of using offsite, design teams have the opportunity to schedule and organise the supply chain in a more effective way. However, this may put pressure on the designers to finish their designs very early. There is often a danger that the client may change their mind, and the contractor may end up with many
redundant precast units and unexpected costs after the fabrication process has started. Yet, there are cases where contractors would fit these unwanted units into other projects.

The location of the project, even the country where it is taking place, can affect the cost, which may vary significantly. Some countries in the Middle East have extremely cheap labour, and in places where local natural rock armour cannot be found in the scale needed, concrete is employed (Paper 2 - Vernikos et al., 2012a). Depending on the local labour cost or other factors mentioned above, either precast or in situ concrete is used. It has been documented in this research that there are other factors which affect material costs; for example, “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” (Paper 2 - Vernikos et al., 2012a). In the UK, rocks of the required size and quality may be available from quarries nearby, or precast units may be sourced. Nevertheless, in case it is not possible for precast units to be delivered by sea, these solutions would be considered unrealistic, and these units would 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. An important issue is the depth of the water around the construction site. A major difficulty in using offsite precast is the planning constraints on account of its ‘industrial look’ (Paper 2 - Vernikos et al., 2012a). The UK government agency responsible for the environment has shown preference in employing natural rocks to either in situ 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, offsite is still generally considered as an innovation. Different countries have different drivers and barriers. “The calculation of logistic costs is a grey area”, reported by Vernikos et al. (2012a). It is not easy to provide cost breakdown, even for clients, since transportation owner operators keep accounts secretively as there is commercial interest, and there is great competition due to the fact that there are only four or five leading logistics contractors influencing the market all over the globe.

4.2.2.2 BRIDGES

Bridges are different from any other subsectors because they inherently use offsite. This research focused on short-span bridges, which represent the majority of the workload in the case study firm rather than large, high-profile projects. The benefits of offsite identified by the interviewees reflect all those identified in the literature. The design and method of construction are governed by project limitations. In most subsectors the design is cost driven, on the contrary 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 is currently available in all Asian markets, which is disliked because they see the maintenance works as a hazard and liability.

4.2.2.3 RAIL

Rail is a subsector that works collaboratively with others, such as bridges, tunnels and buildings. Therefore, it is difficult to identify the precise percentage of offsite used in the sector. Technological improvements in automation have allowed work to be mechanised and have
reduced cost and health and safety risks, especially in track maintenance with prefabricated components. The predominant benefits of offsite construction identified include the improvement of health and safety and a reduction in construction time and cost. 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.

4.2.2.4 TUNNELLING

Tunnelling is a segmented subsector. Parts of the sector, such as micro-tunnelling, have been using offsite construction for many decades (Chung et al., 2004), and it is clear that offsite was the norm for both microtunnelling 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 road tunnels. These segmental tunnelling techniques are considered innovative (Ogborn et al., 2010; Paper 1 - Vernikos et al., 2011). The longest segmented tunnel in the world was completed in August 2011 in the UK, reaching 126 metres (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. With regard to conventional tunnelling, offsite construction is mainly used for bored tunnel linings, including segmental precast concrete or cast iron rings. Overall, its advantages include structural stiffness (Deming and Houmei, 2000) and quick mechanised installation in bad ground conditions. The installation is made exceptionally easy with sophisticated automated tunnelling machines.

4.2.2.5 URBAN WATER

The urban water subsector 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 were increasingly demanding options that would bring down construction costs. The senior staff, aiming to sustain the firm’s competitive advantage, are theoretically aware of the benefits of offsite as portrayed by the literature. Offsite solutions, such as pipe jacking and reinforced concrete manholes, were used in the past, but they are not considered innovative. More recently, modular solutions for assets, such as pumping stations, have entered the market.

4.2.2.6 WATER AND ENVIRONMENTAL MANAGEMENT

Water and Environmental Management (W&EM) subsector 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 improved control of environmental impacts and cost reduction. The interviewees had difficulty in differentiating between offsite construction or prefabrication with standardisation. Offsite units, which are 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. In conclusion, the client drive need for improved best practice formulates a fertile environment for offsite implementation in this subsector.

4.2.3 CONCLUSION

The appreciation and usage of offsite varies greatly within subsectors. Offsite construction is not considered as an innovation in the maritime, bridge and tunnelling subsectors. The two
subsectors that this case study revealed with greatest potential for further research were bridges and water and environmental 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 the team’s experience regarding offsite. Water and environmental management is still an emerging subsector for offsite development. Recent requests for flood defence systems, combined with government pressure for minimising construction costs, have forced the sector to look for more innovative solutions. As the subsector has no underlying historical offsite development, the supply chain is free to move across other subsectors in a quest to develop products and services to best cater for clients’ needs. Standardised design in collaboration with ‘ex situ’ (on-site but not in position) fabrication will help minimise costs and reduce disturbances.

4.3 OFFSITE IN CLIENT AND OWNER/OPERATOR ORGANISATIONS

Nowadays, most engineers are aware of the benefits and drawbacks of offsite (Goodier and Gibb, 2007). At the same time, clients who are well-informed and demanding encourage the adoption of innovation (Gibb and Isack, 2001). Moreover, with respect to the W&EM, client organisations seem to recognise the advantages and disadvantages of using offsite. However, practitioners in the construction industry appear not to consider offsite as a “one solution fits all” standardised solution. This fact accedes to research findings from Goodier and Gibb (2007). Yet it basically applies to the building sector rather than the infrastructure, whereas offsite solutions such as precast concrete are regarded as common practice by some parts of the civil engineering sector (Paper 2 - Vernikos et al., 2012a). Consequently, offsite in the W&EM sector is not considered as innovative. Clients within the W&EM attempt to incorporate offsite driven by standardisation into their project processes after having assessed offsite in an integrated and comprehensive way.

The findings of this section were based on three case studies. A combination of semi-structured and unstructured interview methods enabled maximum input from the six interviewees (Glaser and Strauss, 1999). The interviews were recorded and transcribed. A group discussion followed with the three client directors, three project managers of major projects and the global innovation director. The research was part of WP3 and is presented extensively in Paper 3.

4.3.1 BACKGROUND

Taking into consideration that the majority of the UK’s water supply and sewage infrastructure has been constructed in the 19th or early 20th century, the network has been worn, and according to the HM Treasury (2010a), significant updates are now seen as necessary. In addition, the manner in which the industry perceives the management of infrastructure assets has practically altered, especially in the past 50 years. As a result, infrastructure assets are not considered as unconnected structures anymore but as part of a network which is interconnected and influences each other (HM Treasury, 2010b). There have been moderate estimates that £45-50 billion in the W&EM sector will be spent in the UK by 2020, and this is 10-11% of the overall spending over its infrastructure, Helm et al have indicated (2009). The current annual spending in the sector is £4 billion for 2010–2015, but it is expected to increase as projects such as the Thames Tideway commence. The construction industry is under extreme pressure to reduce costs since, according to the Eurostat Construction Price survey, the UK has the fourth highest civil engineering costs (Eurostat, 2009).
A decrease of 80% in greenhouse gas emissions has been decided by the government to be reached by 2050 (Climate Change Act, 2008). The W&EM sector is at the centre due to its direct link with environmental management, and therefore, it has been pressured to play an important role towards reaching this target by ensuring low-cost delivery, low carbon footprint and good quality infrastructure by advancing their functions and processes (Water UK, 2006). Furthermore, the possibility of extreme weather phenomena has to be taken into serious account. The UK infrastructure will be safely secured due to the fact that extreme weather conditions and their impact on the sociodemographic unexpected evolution are anticipated by the Meteorological Office (MET) as well as the Chartered Institution of Water and Environmental Management (CIWEM). Peter Hansford, who was appointment as the Government’s chief construction advisor, challenges the industry to increase value for money and at the same time reduce significantly carbon in construction (Hansford, 2011).

There has been an initiative to improve the regulatory regime for the water sector in order to assist with the current industry demands. Thus, the Council for Science and Technology (CST) has initiated modifications in organisational processes with the ambition to promote innovation using new technologies, with the aim of encouraging the supply chain to acquire more effective, viable and sustainable solutions. At the moment, the 5-year regulatory review period (HM Treasury, 2010c) prevents the implementation of innovative solutions. Besides, a reward action has been adopted by the CST for any water and sewerage companies that invest in order to improve their solutions by making them sustainable as well as by specifically reducing carbon emissions (CST, 2009). All these coincide along with research evidence reported by the Institution of Civil Engineers (ICE, 2009; ICE, 2011).

4.3.2 FINDINGS

Literature suggests that offsite has three most essential assets: time, quality and cost (Gibb and Isack, 2001; Goodier and Gibb, 2007; Venables et al., 2004). Thus, the major benefits of offsite discussed in the study applying to the W&EM sector are based on decreasing costs, minimising environmental impact and eliminating public disturbance linked to the reduction of on-site works.

The supply chain is seen by clients as able to develop its program in a much more efficient way if standardised designs are employed depending on the type of “frontage”. Both client and supply chain staff that contributed to this study had difficulty in differentiating between offsite construction and standardisation.

Infrastructure projects are usually considered unique; however, the creation of standardised designs is not believed by clients to influence savings directly. Yet what is predominant here is that they are expected to result in cost minimisation in future projects, concurring with similar evidence in other sectors (Gibb and Isack, 2001). Particularly, on account of pressures from the Government, client organisations claim that expenditure is not always the most dominant factor. In fact, clients state that environmental impact is much more important in this particular sector. Nevertheless, in practice, the data collected does not comply with this argument. This is not surprising since non-immediate benefits have been seen before as 'merely alluded to, or disregarded' (Blismas et al., 2006).
The fact that offsite construction is considered to improve sustainability is a key element, discussed by many as a driver (Blismas et al., 2005; Goodier and Gibb, 2007). The basic aspects involved here have to do with reducing waste, noise and public disturbance (Blismas et al., 2005). These reductions derive from the closely monitored manufacturing process in a factory-like environment. Yet, much more research is needed to look into these areas (Gibb, 2001). Sustainability issues may integrate environmental, social and economic aspects. There is always a main concern as regards construction in general, which is related to materials waste; nevertheless, offsite construction is capable of minimising it, as the design of an offsite solution incorporates manufactured materials, and this results in the reduction of programmed wastage (DTI, 1998). However, research findings have recently indicated that offsite construction has not considerably addressed environmental issues (Larsson and Simmons, 2012). More specifically, in the W&EM sector the goal of decreasing the environmental impact has to do, on the one hand, with the reduction of rework and, on the other, with the expectation that offsite designs have more potential to be implemented (Paper 3 - Vernikos et al., 2013a). There are clients who claim that a 60% elimination of embodied carbon has been achieved by employing 70% offsite in the product-based water treatment plant.

Many barriers to standardisation documented in CIRIA (2001) and by Pasquire and Gibb (2002) have been addressed by W&EM clients (Paper 3 - Vernikos et al., 2013a). Clients have attempted to create a process where a product is developed and then accompanied by a ‘standard work’ manual that assists in the uptake of the product (e.g., Midi Submersible Pumping Station and Product Installation Guide). This attempt relates to clients’ ‘route to continuous improvement’, which one could compare loosely with the CIRIA Client’s Guide and Tool Kit (2001), which aims to increase standardisation and pre-assembly of assets, focusing predominantly on the building sector. Furthermore, offsite has been hindered by approval processes in infrastructure which have acted as a barrier to its realisation (Paper 1 - Vernikos et al., 2011), and clients tend to resist change because of the past negative image of offsite solutions (Venables et al., 2004). In addition, certification is not common for offsite solutions in infrastructure as they are seen as one-off projects. Nevertheless, it has recently been required by certain industry organisations (e.g. Buildoffsite) since in the building sector most of the suppliers have their products certified, according to the data of the proOSPa survey (Goodier and Gibb, 2007). Nevertheless, what has increased clients’ trust so that they feel they do not necessarily need certification is the adoption of volumetric (e.g. pumping stations pods, adjustable manholes) and non-volumetric (e.g. treatment tanks) solutions, which has recently been advanced in the W&EM sector. Trial construction, trial assembly and full-scale testing have been used to reinforce these innovative volumetric and nonvolumetric solutions and to develop clients’ confidence.

The one who managed to attract the construction industry’s interest in partnerships was Latham (1994), who saw them as vehicles for progress and innovation, even if he was not the first to support this view. On the same line, Egan (DTI, 1998), a few years later, carried forward the idea of supply chain collaboration by attempting to correlate the evolution of modularisation and standardisation in the United States as a way to reduce costs. Only two years later, the ideas derived from these two publications were realised when the W&EM sector started an innovative set of projects following the Movement for Innovation (M4i, 2000a; M4i, 2000b). These projects demonstrated efficiencies by using partnerships, even before having incorporated any offsite solutions yet in their delivery mechanics.
Conventional construction projects employ a linear-phased approach which is based on feasibility, design, tender, construction, handover and operation. This process has intrinsically been ineffective for achieving innovation since improvements from the use of novel materials, efficient scheduling and solutions cannot be materialised in the design stage unless the contractors or suppliers are involved. The design-and-build contract can be an alternative approach, which calls for increased collaboration between supply chain partners in the early stages of the delivery life cycle of an asset. However, challenges occur when, having bid on low margins, the contractor seeks to increase profit from higher margins on any later change through the project (MacKenzie and Tuckwood, 2012).

Gibb and Isack (2001) discuss the clients’ belief that the fragmentation of the supply chain poses challenges to offsite. Yet, gradual efforts have been made by W&EM clients to consolidate the supply chain (Anglian Water, 2012) by creating major programmes in the form of ‘delivery partnerships’. The goal of this kind of partnership is to develop cooperation models throughout the supply chain, based on successful examples from the building sector, which have approached construction at a program rather than project-by-project basis, as primarily exercised in the case of BAA’s Terminal 5 (Pryke, 2009), although the idea behind this model apparently lies on a realistic appreciation of the priorities of all parties involved from the very beginning of the project. This has taken a long time to come to fruition as offsite construction, coupled with supply chain partnerships, were identified as key to improving construction processes by Egan in 1998 (DTI, 1998).

### 4.3.3 CONCLUSION

The HM Treasury report (2012) on environmental networks states that smoothing the investment cycles in the W&EM sector could provide a better environment for innovation to flourish. The current investment process makes clients and therefore the supply chain adopt a project-by-project approach to solutions rather than a holistic and systemic approach. The supply chain claims that cyclical investment has been a hindrance to innovation and overall cost reduction, and although this HM Treasury report is addressing the problem, more action should be taken. It is expected that a government report would be available in 2013, focusing on new infrastructure procurement routes that would further address the issue of cyclical investment (Water UK, 2012).

W&EM clients have been driving offsite solutions by creating a platform for ‘product-based delivery’ and ‘product integration’. W&EM clients claim that this can be achieved by creating a ‘product catalogue’ alongside a knowledge management system that ensures continuous improvement. Nevertheless, it is admitted that this is not yet the standard work process, although there are few ‘best practice examples’. The success of the increasing usage of offsite in the W&EM sector is yet to be confirmed as most of the data currently available are based on anecdotal evidence only. Significant steps have been made, however, to standardise and homogenise the supply chain by improving the procurement processes. Modular offsite solutions such as pre-assembled pumping stations are a good example of cross-sector fertilisation of innovation as they can be compared with, and can find resonance with, solutions for the building sector (e.g. multiple service distribution modules).
4.4 OFFSITE IN CONSTRUCTION FIRMS

4.4.1 BACKGROUND

This section presents findings from WP2 as presented in Paper 4. This work package started with a literature review, including a content analysis of industry reports (i.e. annual reports, company websites and business strategies). After the innovation strategies of the six leading UK contractors were reviewed, one was chosen to be investigated as its strategy focused strongly on offsite (table 4.1.). Nine members of the staff were interviewed, representing a variety of seniority levels and roles within the firm. Semi-structured interviews were conducted. The interviewees’ responses were compared against the firm’s strategy and the literature, in order to allow triangulation of data (Glaser andStrauss, 1999).

Table 4-1 Summary of the leading contractors’ competitive advantage propositions according to their strategy or annual reports from 2011 and 2012

<table>
<thead>
<tr>
<th>Competitive advantage stated in company literature</th>
<th>Contractors</th>
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<td>A</td>
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<tr>
<td>Sustainability</td>
<td>X</td>
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<tr>
<td>Quality</td>
<td>X</td>
</tr>
<tr>
<td>BIM</td>
<td>X</td>
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<tr>
<td>Culture</td>
<td>X</td>
</tr>
<tr>
<td>More comprehensive capabilities than competition</td>
<td>X</td>
</tr>
<tr>
<td>Asset Management</td>
<td>X</td>
</tr>
<tr>
<td>While-life cycle services</td>
<td>X</td>
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<tr>
<td><strong>Offsite construction</strong></td>
<td>X</td>
</tr>
<tr>
<td>Supply chain engagement</td>
<td>X</td>
</tr>
</tbody>
</table>

4.4.2 FINDINGS

The construction firm investigated was firm D. In this case study firm, various benefits of offsite were presented in the company’s strategy; six aspects of the strategy were considered—three were strategic objectives with offsite perceived as a core process, commercial benefit and contributing to corporate cost savings, and three were benefits on projects level which included quality, safety and sustainability improvements. The interviewees thought that the strategy with a sole offsite focus gave the firm a slim edge over the competition. When asked whether the aim of the firm’s strategy was achievable, the general response was positive, but with conditions. A limited number of responders were entirely sure that the aim could be achieved with the majority of them providing examples which demonstrated the fact that the strategy was had “over-expectations”. The suitability of all project types was mentioned; not all projects benefit from offsite solutions, such as refurbishment projects. Examples were provided where the site team found the utilisation of offsite solutions on projects to be challenging, particularly where assembling prefabricated components indoors was impractical. This supports Blismas et al.’s (2005) conclusions that projects should be considered individually before offsite is recommended.
The barrier most commonly perceived by contractors was the up-front cost to set up a manufacturing facility. An additional barrier to the firm’s offsite strategy in the case study was the availability of good external specialist suppliers. By using only an internal source of manufacture, there was a high risk that problems at the source would affect all of the supplied projects. Strong management of information and quality within the manufacturing facility is needed to combat this. The initial cost to develop offsite capabilities can be seen as unnecessary if the production costs are not cheaper in the long run, but it is worth noting, as stated by a few of the interviewees, that when components are self-produced, money is being kept within the contractor’s business, which can have positive impacts on cash flow and company turnover.

Surprisingly, examples were provided when offsite was sometimes seen as a potential barrier to winning work. Care, therefore, had to be taken to ensure that offsite was not employed where an in situ solution would be more appropriate. Further barriers also included geographical location, as some projects may be too far for delivering components. The time delay for successful training of a manufacturing workforce must also be considered and was cited by two respondents. The case study contractor was a privately owned manufacturing company, whilst the contractors that had similar levels of turnover and delivered similar projects were publicly owned by shareholders. The requirement to satisfy shareholders was seen to be a barrier to significantly changing a company’s business model and strategy in order to adopt a more offsite capability. Finally, many felt that smaller companies did not have the necessary volume of work to make offsite use economically viable.

With regard to the implementation of the firm’s offsite strategy, it is evident from the interviews and the company strategy that the firm is fully committed to employing various methods. These include a company intranet, which provides basic information and raises awareness of offsite best practice. The firm also has a graduate development programme that focuses on educating inexperienced engineers with regard to the importance of offsite and its application. The company holds two road shows every year, where business leaders and directors communicate with all employees, with the aim of motivating the staff and keeping them focused on the firm’s offsite targets. This provides a structured way for project leaders to communicate to site teams particular offsite solutions that may be best for individual projects.

### 4.4.3 CONCLUSION

Three main strategic measures appear to be required in order for a major contractor to successfully obtain an offsite capability. These include the following:

- A leadership team that is committed to achieving innovation through offsite, exhibited in this case through the development of an in-house consultancy cross-cutting the organisation, with an emphasis on innovation.
- Clear communication is needed to employees at all levels regarding the intention to use offsite, for example, communication best practice examples from project leaders to site teams on individual projects and training of graduates who may go on to become future site managers or business leaders. This commitment to communicate the importance of offsite was also exhibited here through the firm’s online intranet and in-house catalogue of available offsite components.
- A commitment through investment in R&D and a clear business strategy.
4.5 **OFFSITE AND BUILDING INFORMATION MODELING**

This chapter presents a summary of the research undertaken as part of WP4. The analysis and findings are presented in detail on Paper 5. This UK-focused research delved into how innovation initiatives such as BIM and offsite can be considered together, thus allowing a leaner design and a greater integration of lifetime project data and more novel technical solutions. Grounded theory was applied in this research to allow for insights into investigating the emerging industry processes, while avoiding the adjusting or steering of data towards existing theoretical frameworks. Twelve semi-structured interviews were conducted with subject matter experts representing leading UK construction contractors and consultants, global software vendors, UK engineering industry institutions and the UK Government. Key themes that emerged from the thematic analysis of the interviews show the importance of configuration and interface management, information data flow, project management and delivery, procurement and contracts.

4.5.1 **BACKGROUND**

Research literature (Wix, 1997; Venables et al., 2004; Blismas et al., 2005; Goodier and Gibb, 2007; Nadim and Goulding, 2010; Bew and Underwood, 2010; Larsson and Simmonson, 2012) and industry reports (National BIM Report, 2013; McGraw Hill Construction, 2010 and 2011; Miles and Whitehouse, 2013) analyse barriers, drivers, implementation techniques and case studies for both BIM and offsite. Many organisations and academic and industry experts have attempted to define the relationship between BIM and offsite.

Regarding term and definitions, BIM in this research is seen as an umbrella term for object-oriented modelling that relates to both vertical (i.e. buildings) and horizontal (i.e. railway, highways, etc.) infrastructure, where the objects have extended attributes that can be leveraged to understand the content of a design and allow for a consistent platform of communication throughout the supply chain. Similar to BIM, Offsite has been promoted by the UK Government for generations, albeit using different terms such as prefabrication, preassembly, etc. (Murray and Langford, 2008). In 2002, the Department for Trade and Industry (DTI) collaborated with the Engineering and Physical Sciences Research Council (EPSRC) to develop a programme of works, the Innovative Manufacturing Initiative (IMI). The IMI funded a theme called Meeting Clients’ Needs through Standardisation (MCNS), which orchestrated a group of focused calls for research programmes. The last two programmes funded predominantly by the Department of Trade and Industry’s (DTI) Partners in Technology programme (currently known as Department for Business, Innovation and Skills, or BIS) were Avanti and PrOSPa. Avanti’s core aim was to investigate and encourage collaboration through the use of computer-aided design (CAD) by arguing that managing information databases was more efficient than managing ‘drawings in a cabinet’ (Construction Project Information Committee, 2007). Avanti supported early access to information from all parties of the supply chain and work protocols, promoting improved communication and common information models, and was a stepping-stone on the way to the current Government BIM initiative. PrOSPa aimed to encourage offsite solutions across the construction sector (Goodier and Gibb, 2007). PrOSPa was the predecessor of the industry-focused organisation Buildoffsite (www.buildoffsite.com). Both the Avanti and PrOSPa programmes focused their work predominantly on the building sector rather than on civil engineering.
4.5.2 **ANALYSIS**

From the research through emergent thematic analysis, the following key areas of interest emerged:

**Configuration Management** – The construction industry is becoming more digital and therefore will progressively be more into automation, computerisation and manufacturing. When large numbers of offsite components are ordered, contractors are challenged with locating and identifying potential defects within multiple large and complex construction sites. BIM enables technologies to track real time which bunch went to which site and from then how many were installed and where. Therefore, embedding this information gives contractors greater control over offsite units, increasing their confidence by reducing risk, thus resulting in more adoption of offsite.

**Construction Management, Scheduling and Planning** – It is believed that offsite has long ‘lead-in times’, which are a greatest disadvantage, and if not managed correctly, offsite could add costs to the project. To prevent significant delays in the construction phase, information needs to be accurate, finalised and ready far in advance. Participants claimed that BIM enables them to have a better programme that includes the manufacturing process, the delivery and the installations linked with the design. All participants agreed that the supply chain benefits from timely decision making through early contractor involvement, which is encouraged by BIM. Opportunities for offsite can be identified and introduced as under a BIM working environment; because of this, early decision-making-process changes to the design can be made sooner. Finally, with BIM participants claimed that it is possible to assemble the structure virtually, observing the process before it commences on-site.

**Interface Management and Information Data Flow** – All participants perceived BIM to promote collaboration in the earlier life of the project, which is necessary for offsite implementation (Gibb, 2001). Contractors predominantly are adamant that BIM will help establish relationships, and then those relationships will help identify potential for offsite. The participants believed that working under a BIM environment was a way to be ”exposed” to areas where offsite could add value. The way information is currently communicated in the construction industry was seen by all as a big issue. There are very abrupt handovers of information, usually in document form which needs continuous checking. Minor mistakes in design or misprints could lead to an increase in cost and construction time, especially when using offsite, as there is little or no flexibility when the components arrive on-site. BS1192 (BSI, 2007) makes a distinction between someone’s private work, the shared work in progress and the published work. Within that ‘shared’ environment, automatic checking and peer review is viable, allowing issues to be identified in advance and discussed earlier in the process. However, participants were unable to supply evidence of current projects.

**Procurement and Contract** – Participants believed that BIM should be a catalyst for changing the way the industry procures. It was evident to them that current procurement methods hinder the development of offsite through BIM. Contractors thought that procurement mechanics can really affect the development of offsite and highlighted that design and build contracts enable BIM-driven offsite. Consultants agree that early contractor involvement ”can help to identify when offsite can be of value”; therefore, appropriate contractual agreements will enable ‘earlier’ decisions, which is ‘the key’ to successful implementation.
Object-Oriented Design – This theme included areas such as virtual object design, virtual libraries and assemblies. Software experts admit that current BIM software is not that great for assemblies; nevertheless, BIM has the potential to promote offsite by identifying repetition, which will enable greater cost saving through mass customisation. According to the UK Government participant, the Technology Alliance Group is currently tasked by the UK Government to challenge the way software vendors allow ‘BIM libraries’ to be created or other ways of grouping components or systems. The real challenge is on the way the software will manage assemblies, what kind of assemblies may occur, what kind of components may contain and how they can be shared. The UK Government claimed that they appreciate the potential for offsite, and they are aware of its documented advantages, but they are not willing to regulate or demand a specific software or technology to promote it.

The challenges include the following:

- The type of functions or technology that will be used by the application to create and save offsite components as a library resource
- Whether the assembly will override the content or vice versa

Exporting and sharing assembly data in a BIM environment is considered by respondents an issue despite COBie’s and IFC’s implementation. BS8541 (BSI, 2012) was created to assist in this computerised data exchanging environment aiming to encourage manufactures of offsite components to recommend designs, fix costs and demonstrate the quality of their products through a template. Nevertheless, manufacturers are wary about this process as the information required from them is not clear and intellectual property (IP) issues arise. The templates mentioned in BS8541 (BSI, 2012) were criticised as having a lot of attributes but no values.

Modelling – This theme included areas such as modelling capabilities, model quality and data richness. All participants claimed that BIM enables offsite because of the 3-D elements that allow greater visualisations. Nevertheless, increasingly, some contractors find that when models are received after the tender, they have little value. The model is vital for construction programming, and therefore, the designer has influence in that process and is the key for lead-in times when considering offsite construction.

4.5.3 Findings

The participants in this research attempted to identify evidentiary examples to prove that BIM enables, promotes, increases or improves offsite, but apart from some aspects of key infrastructure projects, no evidence could be provided. The UK Government provided examples where projects started using BIM from RIBA-Stage C (concept) phase and this was deemed fundamentally flawed. Therefore, based on this principle; some participants’ examples were disregarded as their BIM elements were merely 3D visuals or the BIM implementation was encouraged not for its efficiencies but for commercial reasons.

Offsite is a more “familiar” concept to the civil engineering sector than BIM, with precast concrete elements and bridge construction or tunnelling often employing offsite (Paper 2 - Vernikos et al., 2012a). However, throughout the data collection process of the research summarised in this paper there is a confusion of the terms standardisation with prefabrication and the term offsite was not clearly understood. Economies of scale are achievable through standardising offsite elements and BIM may influence the process drastically, yet the one does not automatically lead to the other.
4.5.4 CONCLUSION

After analysing the responses of twelve of the BIM and innovation directors representing leading UK consultants, contractors, software vendors and construction industry institutions, it is evident that there is a clear belief that BIM will improve and increase offsite construction in civil engineering. Nevertheless, the participants in this research attempted to identify evidentiary examples to prove that BIM enables, promotes, increases or improves offsite; but apart from some aspects of key infrastructure projects, no evidence could be provided. The UK Government provided examples where projects started using BIM from RIBA-Stage C (concept) phase, and this was deemed fundamentally flawed. Therefore, based on this principle, some participants’ examples were disregarded as their BIM elements were merely 3-D visuals, or the BIM implementation was encouraged not for its efficiencies but for commercial reasons.

4.6 OFFSITE IN GOVERNMENT, ACADEMIA AND INDUSTRY RESEARCH ORGANISATIONS

4.6.1 INTRODUCTION

Industry-support organisations have great responsibility and can make a significant difference in materialising offsite in infrastructure. Such organisations include Institutions (i.e. the ICE, IStructE, IMechE, CIOB and RICS), trade organisations (i.e. BSRIA, TRADA, SCI, British Precast), industry research organisations (i.e. AIRTO, CIRIA, Constructing Excellence), lobby groups (e.g. Buildoffsite, etc.) and Universities (e.g. Loughborough University). During the workshops that took place in WP5, the impact and effect on realisation offsite of such organisations was reviewed.

4.6.2 FINDINGS

Support organisations, in collaboration with the Government, have the ability to develop industry-wide guidelines similar to the BIM initiative. The uptake of BIM has been extremely rapid over the past few years, and a similar approach could be adopted for offsite. Throughout the industry, BIM is seen to enable the use of offsite (Paper 5 - Vernikos et al., 2014a). Data exchange standards and overall interoperability create a robust platform for offsite solutions to develop and eliminate several problems of the past. The government has to be more active with regard to regulating and structuring the process for offsite uptake. More specifically, an industry-wide library of standard products or a public offsite repository is needed. It is best not to call them standard products but parametric components because standard products have negative links to it. These libraries should be shared and downloadable to a computer and should be made available from project to project or company to company. Also, the Government should enable or encourage 3-D parametric prototyping to be shared as standard in a pull-and-use format. Uniclass-type resources should focus more on offsite, and there is a need for industry offsite standards and requirements similar to BS/PAS 1192 for BIM. With the existing technologies, one is able to create a 3-D object with manufacturing data and send it straight for manufacturing. Two of the seven key components through which the government articulates BIM Level 2 is the TSB DPoW and TSB standard construction classification—as this is a classification issue, the BIM Level 2 2016 mandate should resolve it.

A need for a process guide was also identified, which, in conjunction with the industry standards, should develop into something similar to an ISO, similar to ISO BIM (Bew and...
Richards, 2013), albeit without specific percentages of offsite per project but process focused. It is important to have an assurance and accreditation process with set targets and KPIs that the industry can work towards. During the workshops, it was evident that all participants believed that the infrastructure market has the advantage of a longevity of programs, and therefore, it possibly needs the government to step in and help. Moreover, the industry and client organisations need a better structured government investment in R&D.

As a whole, industry-support organisations should focus on public engagement. A focus is needed on changing the image of construction in order to attract higher-calibre multi-skilled individuals. It is important to consider diversity and inclusion in the agenda. The public engagement plan should include social media and general media, not just construction-focused magazines, etc. Media productions such as Grand Designs help change the image of construction with a building focus, but infrastructure still has a long way to go. There are significant differentiators for offsite construction in infrastructure that make it even more viable for infrastructure, and they have not yet been communicated properly. Construction needs a strong communicator and advocate who appeals to broader public opinion. The public engagement plan, coupled with the education plan, should result in inspiring young people to join the construction industry. These bright young minds should be not just civil or structural engineers but also software analysts, mechanical and electrical engineers, etc. It was believed that these new leaders would act as advocates for innovation, understanding the mechanics of offsite and therefore implementing it accordingly.

Finally, an education plan was discussed with academia at its heart. Some participants thought that universities have to change and that they are ‘a bit set in their ways’. It is believed that universities should focus on developing multifunctional, multidisciplinary degrees, and civil engineering courses should include topics such as offsite construction and manufacturing. Other suggestions included mandatory offsite courses in civil engineering degrees and the development of an MSc in offsite construction. In addition to universities, education in schools was discussed, including initiatives such as Lego and Google’s SketchUp. It was also mentioned that even schools should get exposure to offsite by visiting more offsite manufacturing plants, etc.
5 FINDINGS & IMPLICATIONS

This chapter presents the main findings of the research including their impact on the sponsoring industry firm and the wider industry. The research approach, outcome and impact are critically assessed and recommendations are suggested for industry and further research.

5.1 THE KEY FINDINGS OF THE RESEARCH

The key findings, once the main body of research was completed, were verified through three industry workshops during the triangulation phase of the research project. As stated in Chapter 3, each workshop included 15-25 subject matter experts (e.g. Managing Directors, Innovation Directors, etc.) from the industry representing client, contractor, sub-contractor and consulting firms, in addition to universities and institutions, such as the ICE and RICS. Additional data was also collected after each workshop via telephone follow-up interviews in order to clarify areas of ambiguity and obtain additional evidence. The conclusions of these workshops were divided into two main categories: one focused on a top-down approach at the organisation level and the other on a bottom-up approach concentrating on the project delivery level. Three workshop reports were produced (see Appendix F, Appendix G, Appendix H) which discussed the methodology adopted in each workshop, highlighted key discussion points and summarised initial conclusions. Following the analysis of the data Figure 5-1 and Figure 5-2 were created in order to communicate the findings of the workshops in a more concise way.

5.1.1 DEFINING AN OFFSITE STRATEGY

This section describes the actions that should be undertaken throughout a client or delivery organisation, derived from recommendations based on the viewpoints expressed by subject matter experts in the workshops and interviews described above.

5.1.1.1 Organisational Strategy Recommendations

The first action for an organisation, irrespective if it is a client, a consultant or a contractor, is to create an offsite strategy. Different organisations have different targets and structures, therefore focus groups should be held with senior management staff that will concentrate on discussing organisational processes with the aim to craft the offsite strategy. It is critical for the strategy to present a high level of buy-in and a clearly defined business vision led by senior management. After having taken into consideration the company’s priorities, the strategy will be developed stating the reasons, and the needs for change, along with incorporating the benefits, drawbacks, drivers and barriers. One of the aims of the focus groups should be to ensure that a framework is available to the project delivery staff that encourages standardisation of the offsite processes. It is important not just to focus on the standardisation of components but also on the processes for project delivery and governance, as discussed at the workshops. In particular for infrastructure, the focus groups should identify repeatable processes rather than products themselves, for example, processes that may potentially encourage the installation of different products in a way similar to the building sector’s facade solutions.

The offsite strategy should include an R&D fund which will have the capacity to unlock and mobilise “idea generation” and help enable new offsite techniques and their introduction, as shown on the formal process map in Figure 5.1. The R&D fund should be assessed annually.
and be amended accordingly after reviewing the KPIs, the business and market needs, and the previous year’s overall performance. Part of the strategy should also be a recruitment and retention plan, focusing on hiring staff that can perform offsite capabilities. Firms with effective offsite capabilities, as well as the ones that show interest or even make plans to employ offsite, should “recruit staff with domain knowledge”, as identified at the workshops.

![Figure 5-1 A formal process map for offsite corporate strategy.](image)

A key part of the offsite strategy should be a training and education plan, with the aim of growing “organic capabilities”. As the offsite strategy is being implemented, new roles will be created, with new responsibilities. When these have been identified, an associated training scheme should be developed. The education plan should not focus just on technical staff, but also on senior management, in order to ensure an ongoing offsite culture and ethos. The training plan should have an organisational culture focus and a general goal to raise awareness regarding offsite throughout the firm. The management strategy and an organisational behaviour which defines the culture and ethos are interlinked (Buchanan and Huczynski, 1997; Stacey, 2000). Implementing an offsite culture throughout an organisation requires the right people and the right approach. As part of this, appropriate training, expertise and experience are all required, as well as clients implementing offsite appropriate procurement policies. It is important to be clear to all staff that the offsite strategy is not mandating offsite, but enabling and encouraging offsite through continuously informing and educating staff on the available options and their benefits. This will result in the perception that offsite should be considered and deployed where it adds value. The strategy should also look at how to create multi-functional high performance teams in the offsite area.

It is important for the strategy to incorporate and apply metrics on the offsite initiative within an organisation, and to be able to measure success (or failure). KPIs should be applied annually, and drive behaviours. Results should be unambiguous, articulated and published. Measuring
and demonstrating continuous improvement will reinforce the confidence of senior staff, resulting in increased commitment to the initiative, assuming that the KPIs demonstrate improvement. By identifying good practices, celebrating and reusing them, a firm can develop better results and continuously improve. Firms should embed within their offsite strategy a co-operative approach rather than a competitive one, both internally across teams and externally with different partners.

To maintain momentum and implement the strategy effectively, a series of offsite-focused market/sector implementation groups should be created, dedicated to delivering the actions of the strategy. These groups, having an internal focus, should include a variety of senior staff and team leaders, not focused solely on their technical expertise but also on their influence, motivation and beliefs. The groups should consider defining roles for offsite responsibilities and the creation of collaborations with tier 2 and 3 contractors (suppliers) and analyse the supply chain development process in their market/sector. The suppliers have three key requirements – i) clear communication, ii) visibility/certainty of demand, and iii) early involvement. Suppliers are worried that they would give their ideas to the clients and the client would then go and procure them elsewhere at the cheapest possible price; therefore, informed clients are also important - clients who appreciate and support the offsite procurement process. In addition, tier 2 and 3 contractors need to understand the direction in which the clients are heading in order to provide the appropriate solutions for their needs.

When the above has been discussed and embedded in the organisation’s offsite strategy, the next step would be to create an ongoing Offsite Excellence Group, as per Figure 5.1. This group would have the expertise, commitment and responsibility to advise the business on how to deploy offsite effectively within the organisation and their projects. This team would be the technical experts who would continue to engage with the contractors and specialist suppliers, ensuring that they are aware of potential new innovative solutions. Engaging and collaborating with the industry should include tier 3 contractors as they will be delivering a significant part of the offsite solutions.

The aforementioned offsite strategy considerations apply equally to client organisations as to consultants. Clients have the opportunity to influence decisions and therefore carry great responsibility. First, it is imperative that they allow the supply chain to have visibility of the work volume in the coming years. This will increase the confidence of the supplier to invest in product delivery as the knowledge of the order certainty will help them ensure security. Therefore, large industry programmes and return/repeat clients have the potential to obtain greater benefits from offsite. Client organisations should also clearly articulate and estimate the expected benefits, both on a practical and reputational level, from their deployment of offsite. This could not only be cost, quality, or time focused, nor even a combination of them, but also better collaboration of all parties involved with less supply chain tensions and disputes. This process applies for both client and delivery organisations. The clients, through this offsite driven engagement process, would hold their supply chain accountable for achieving their targets.

Summarising this section presenting the organisational strategy recommendations based on the three industry workshops, key actions have been to define the vision and create the offsite strategy. Identification of roles and selection of staff has followed. Thus, these would populate the dedicated focus groups which would help promote offsite, and then drive it within the organisation by implementing the strategy, advising with concise feedback and developing that
vision, as presented in Figure 5.1. It is important that senior management allocate funding for the initiative, including for R&D. It needs people and behaviours that can embrace the “offsite mentality”, together with multi-skilled people to grasp the responsibility, and to lead and implement it.

5.1.1.2 Project Level Recommendations

The section describes the actions that should be undertaken during the lifecycle of a project so as to enable the application of offsite within the CE&I sector. The project lifecycle is divided into five loosely-defined stages: i) feasibility, ii) optioneering, iii) design, iv) delivery, and v) handover. In all these stages the viewpoints of the client and delivery organisations have been considered during the triangulation workshops. The amalgamation of the data collected from each team during the workshop and their analysis in described below. In order to communicate with more clarity the requirements and needs for offsite on each stage of a project lifecycle, Figure 5-2 was created.

![Figure 5-2](Image)

**Figure 5-2** Offsite recommendations at project level, as created during the triangulation workshops.

**Feasibility Stage**

Having an informed client during the early stages of a project is crucial. The project team should engage early with contractors and clients with the aim to help the client develop a precise specification that will focus on assisting to enable offsite. The project specifications should include performance specifications with a project team target. The client specifications and overall approach should be output and outcome focused. Moreover, offsite construction should be incorporated in the Invitation to Tender (I.T.T) stage as a common practice requirement.
“An offsite informed brief is also deemed critical. Nevertheless, the aim is to have a minimum brief, not prescriptive, therefore keeping the options open for potential project delivery ideas and/or routes. The brief needs to be outcome focused.” Overall collaboration, which should include more specifically partnering, is important. Project values-based (i.e. increased quality of the deliverable) procurement and a procurement process weighted in favour of an offsite solution (i.e. perceiving offsite as a key parameter for decision making in the selection process) would further encourage the project team to prioritise accordingly.

**Optioneering Stage**

When assessing different potential project options the project team should challenge existing approaches against practices that are not “common practice”, and compare their benefits and drawbacks. It is important to encourage true optioneering and attempt to understand the drivers of different options (e.g. cost, time, sustainability, etc.). The aim should be to achieve a balance between cost and value, and not just the cheapest upfront initial option. The solutions chosen for one project may have large financial savings when applied to future projects. The team should focus on “exploiting” existing and/or previous offsite portfolio design options, as there are several currently available for all types of projects in all major infrastructure firms. If this is not sufficient or available, then considering new technologies, and engaging with suppliers and tier 3 contractors, will add to the list of potential options available. This process will also allow the project team to understand better the supply chain’s capacity and capabilities, or lack of them.

Other considerations for the project team are an onsite industrial construction approach (Paper 4 - Vernikos et al., 2013b), as logistical challenges may not allow for large prefabricated components to be transported from offsite facilities. There is no need to fabricate components in factories far away if it makes more financial and practical sense to fabricate them on, or very close to, site. Current developments in the adaptation of BIM will enable a parametric object-oriented design where there will be a public offsite repository (Paper 5 - Vernikos et al., 2014a).

**Design Stage**

The use of BIM should be the principal approach at this stage (Morell, 2011). BIM should be used to author models for design, constructability and sequencing. The use of standard specifications and standard products (from product libraries) should help illuminate (or at least minimise) issues in detailed design such as structural clashes of components or logistical challenges. It is important to also complete the majority of the design before delivery starts. Projects reach a point, beyond which, offsite cannot be, or should not be, accommodated; that is, at the preconstruction phase. From this stage onwards it is too late to influence the use of offsite, but rather to ensure that the offsite solutions and processes employed are implemented successfully (Figure 5.2).

**Delivery stage**

The research indicates that the decision as to whether offsite would be employed on a project should have been made by this point, as per Figure 5.2.. The focus at this stage should be on logistics and process control, for example just-in-time management of components and a minimum stock of parts. In general, minimum material and people on site are an important consideration. Nevertheless, until there is a standard approach agreed with specific protocols,
there will be issues with benchmarking and quantifying the benefits. To minimise unexpected challenges it is important to set data rich KPIs. These can be set by the client or by the project team themselves. The constructability and sequencing models created during the design stage should be used to support an assembly mentality. Through BIM, the construction industry can be encouraged more to have an automotive style approach to component assembly. Clients, such as main railway asset owners, are thinking about how lessons from other sectors, such as automotive, may be applied within a railway environment (Paper 3 - Vernikos et al., 2013a).

**Handover stage**

It is important that the delivery team does not just hand over *‘the key to the other side of the table and walk off’*. The industry should embrace BIM’s Soft Landings (Morrell, 2011), where there is a seamless transition of information and data from delivery to operation teams. “Examples exist in the water sector, where several months after handover the operational efficiency drops significantly”. With offsite, and especially with standardised products, the client becomes familiar with how to maintain and operate the assets delivered. Standardisation of processes and components assists users to feel confident with the operations and maintenance processes due to consistency. In addition, within a “BIM environment” as-built models should be provided to the clients, after project completion, with standard documents to support the asset management and operation.

**5.2 IMPLICATIONS/IMPACT ON THE INDUSTRIAL SPONSOR AND WIDER INDUSTRY**

**5.2.1 CONTRIBUTION TO EXISTING THEORY AND PRACTICE**

The majority of research and literature on offsite construction remains focused on the building sector. Most recent literature (e.g. Patlakas et al, 2015; Goulding et al, 2015; Lawson et al, 2014; Taylor, 2010) persists in investigating the buildings sector with a main focus on healthcare or housing.

In the UK, it appears that, despite the increased investment in infrastructure and civil engineering, there is limited academic research on the topic. This occurs despite clear evidence that both clients and the supply chain have been realising offsite in various ways and forms. The findings and conclusions of this research have contributed to this subject area by:

- Clarifying the perception of infrastructure client organisation on Offsite construction and how the perception of accepted risk is influencing decision making.
- Providing guidance and recommendations on creating an offsite strategy across the infrastructure sector.
- Developing a better understanding of the differences of offsite barriers in sub-sectors (i.e. highways, maritime, rail, etc) within infrastructure.
- Clarifying the relationship between BIM and offsite within infrastructure projects and suggested solutions on how they have assists each other.
- Identifying the challenges client, consultant and contracting firms face in their attempt to realise offsite.
5.2.2 Impact on the Sponsor

The sponsor has supported the research despite repeated challenges due to management restructuring and organisation merges/acquisitions (e.g. the acquisition of Halcrow by CH2M). The research helped the sponsoring firm to raise its understanding of offsite, both top-down and bottom-up, including client perception of risk, industry wide offsite requirements, and ways to capacitate them, hence creating a unique selling point. As a result, the sponsoring firm has benefited from:

- Raising awareness regarding offsite benefits and delivery approaches has encouraged project leaders and managers to consider offsite as an appealing option. The awareness raised allowed the sponsoring firm to position for major infrastructure partner roles within both the Transportation and Water business Groups.

- Improving the confidence of staff and motivating them, resulting in a proactive search for past internal offsite case studies and consequently an organic offsite knowledge/skill growth within the organisation.

- Streamlining their innovation strategy, by including offsite as a core area for further development.

- Developing offsite as a unique selling point (USP), which has subsequently contributed to a number of successful bids, winning major infrastructure projects and programmes. These commissions have commences with the clients of both of these motorway and railway projects developing the offsite vision discussed during procurement process.

- The sponsoring firm was seen as a market leader in Offsite Construction within the engineering consultant market resulting in several strategic advisory commissions.

- Increased market visibility, and as subject matter expert consultant, the sponsor provided offsite strategic consulting services both at organisation and project specific level for clients that are owner/operators of linear infrastructure.

Diagrams, such as Figure 5.1 and Figure 5.2 demonstrated the steps and requirements for the implementation of offsite in both projects and company strategies. These were also supported by the workshop reports (Appendix F, Appendix G, Appendix H).

An indicator of the importance and value of the research to the industrial sponsor was the decision to continue with the research, post restructuring of the strategy and management. This level of commitment continued during difficult times economically, which forced the industrial sponsor (Halcrow Ltd) to reduce their number of staff significantly, and resulted in being acquired by another company (CH2M Hill Inc).

Finally, the research led to the creation of several new related roles:

- two members of staff were seconded to a client organisation, and whilst there leading on offsite implementation

- a new member of staff working internally to develop a library of standardised objects to be applied in future rail metro project by design teams, as it is anticipated and indicated in the offsite strategy of the client. The RE contributed to the development of the client's offsite strategy.
This is a clear indication of the increased need for, and interest in, offsite and therefore the current work has undertaken to implement it in infrastructure.

5.2.3 IMPLICATIONS FOR THE WIDER INDUSTRY

During the research, the RE worked closely with several clients in order to understand and define their offsite needs, collect data, and use the research findings to support the clients’ aspirations. One of these clients, via a major railway programme, will be delivering their infrastructure assets with offsite as a key requirement. The client is aiming to save a significant percentage of design and construction costs due to the increased facilitation of offsite. Other advantages that they considered were due to offsite were the minimisation of disruption to third party stakeholders and the public, the maximisation of the whole life cost of the assets, and achieving the highest standards of Health and Safety. This client, with the support of the sponsoring firm, is currently in the implementation phase of the offsite strategy and several tasks have been delegated to client staff and supply chain experts.

Following the support and guidance of the RE, the client is grouping all the structures (e.g. retaining walls, viaducts, underbridges, over bridges, cut and cover tunnels, culverts, etc.) into coherent standard families, thereby reducing the number of different types of structures to be delivered by the supply chain. It is anticipated that several of the structures’ shape and material may be changed in order to improve the consistency and repeatability throughout the whole programme requirements and fit into the proposed standard families. In order to do this, the client was encouraged to take into consideration a series of actions which are currently being delivered and are described below in more detail.

Selection reports are required for the specific sections and structure types across the programme. The output includes the best solution for each of the families, combining architectural, economic (including whole life cost), functional, quality, buildability, sustainability, durability/reliability and safety inputs, with special consideration for prefabricated solutions (Paper 2 - Vernikos et al., 2012a). For each family of structures, a defined engagement with the approvals department of the organisation has been scheduled to take place as recommended by the research (Paper 1 - Vernikos et al., 2011). The general arrangement drawings for the typical structures that are representative of each family identified are currently being produced. Bearing in mind that the programme is currently still at a very early stage, these drawings show the key dimensions and constraints needed to define the structure at the current level of design.

The aforementioned work that took place as part of the research is contributing to the under development client Specification for Civil Engineering Works - currently being finalised. This includes both the design and construction specifications, as well as some specific design details. Other tasks currently undertaking in order to increase offsite on this programme include the production of a risk register which attempts to identify all design, fabrication and installation risks. The risks are appointed an owner and some mitigation measures have been proposed. This was a recommendation drawn directly from Vernikos et al (2011). A “constructability assessment” is currently being produced which includes assumptions for any departures from existing common practice. The client prior to procurement will have defined, and in place, product-focused project specifications and design requirements, deliverable approach statements, a design element schedule, a design element statement, and general arrangement drawings for all the structures that will be expected to be delivered offsite.
In addition to the above tangible example of how the RE used this research to facilitate and support the realisation of offsite in infrastructure, other initiatives were undertaken in parallel. Following the three workshops undertaken at the end of the research to verify the findings, and the recommendations made at the end, the participants developed a series of offsite hubs (figure 5.3). Several of these hubs were created, with some, such as the water hub, having great success by having well attending meetings and progressing with increasing offsite uptake. Following the workshops an initiative commenced with the three main contractors participating in the workshops agreeing to launch an industry focused Offsite Management Academy. This is currently being established and the team of contractors and consulting firms leading on its development are developing the material for the modules and lectures. The focus of the school is to increase the understanding of management staff in consulting, design and architectural firms. The training is online and free for members.

![Offsite hubs and participating organisations.](image)

Lastly, the REs work featured in several industry publications, such as the RICS Construction Journal, the ICE Civil Engineering Journal, the New Civil Engineer, Innovation & Research Focus magazine and many websites of major contractors and institutions (i.e. Innovation Themes, ICE) (Vernikos and Goodier, 2014b; Vernikos et al, 2012b; Vernikos and Goodier, 2014c).

### 5.3 CRITICAL EVALUATION OF THE RESEARCH

The aim of the research was to investigate the scope, constituent components and application of offsite construction in the CE&I sector. This was a complex and challenging task, taking into consideration the breadth of the offsite construction subject area, the time constraints on the project, and the challenges faced by the continuous changes within the sponsoring firm during the course of the research. The limitations below have been identified:

- Throughout the execution of the research a balance between industry and academic focus was required. To ensure that the data was collected and analysed with sufficient academic rigour, at the beginning of each work package a thorough review of literature took place. The literature considered at times was not just based on peer reviewed
journals and conference papers but also on company strategies, industry reports and other non-academic publications. These secondary data sources had to be reviewed with additional focus, and in an objective manner, as commercial and business development bias was common.

- With regards to the primary data, during the data collection process several senior industry subject matter experts at Director level were involved. Unfortunately, not all of these senior experts were available to participate in all of the triangulation workshops. To mitigate this, in addition, telephone interviews were conducted, with the workshop reports being also issued to them for feedback and comment.
- Due to the longevity of CE&I projects, the RE was not able to monitor first-hand the implantation of offsite strategy and hence verify their effectiveness directly. Clients that manage and operate rail and motorway liner infrastructure assets are currently implementing their offsite vision, and the realisation of offsite will be able to be assessed in more detail over the next 5-10 years.

5.4 RECOMMENDATIONS FOR INDUSTRY AND FURTHER RESEARCH

The three workshops conducted during the triangulation of the data provided a good platform for clients, industry support organisation and the construction supply chain to engage and express their current perceptions of future research needs on offsite in infrastructure. Following the recommendations drawn during the research, a series of themes emerged for further academic and industry focused research.

5.4.1 KNOWLEDGE MANAGEMENT

Important issues that needed to be investigated included the knowledge management spectrum and the collection of existing case studies, as well as capturing the knowledge to create a commonly-acknowledged pool of information. All research participants saw the greatest need to “identify best and worst situations for that adoption of offsite”, articulated in a concise way. Secondly, apparent was the need to conduct a thorough gap analysis for offsite opportunities that were sector focused. This should encourage replicability of practices, focusing on what has been used, was successful and can be re-applied elsewhere.

5.4.2 OFFSITE METRICS AND BENCHMARKING

It was evident throughout the research that there was agreement on establishing a set of offsite metrics and a benchmarking system. This should be done by compiling an accurate set of fact sheets and making them publicly available, in addition to setting clearly defined target metrics, such as cost and time (e.g. per meter, per % of design), as well as charges related to preliminary designs and time spent.

To do this, it is necessary to make the existing information and data readily available, while defining a common cross-sector strategy. Once again, quantifying the benefits of offsite (such as gains in time, cost, etc.) was highlighted as being important. It was proposed that the government should be involved in the standardisation by base-lining data collection and demonstrating improvements made because of the offsite construction integration.

The development and use of a widely agreed set of KPIs (i.e. implementation criteria assessment, gateways for go-no go for offsite use, etc) would encourage clients to procure
multiple similar assets through offsite and enable them to compare solutions. Finally, a standardised data capture is required. This could lead to a clear demonstration of tangible wins and losses and how they compare against business as usual.

5.4.3 TRAINING & EDUCATION

The development of standardised solutions from offsite would rely upon an initial training package, as well as the identification of any potential skills gap and of additional training needs. An innovative suggestion was for an industry body to sponsor and develop an offsite construction video game which is to foster a young community of offsite advocates and help bridge the skills gap. It was considered that further work (and a possible case study) is critically needed to investigate the effect of changing skills and the reskilling of employees in the industry, possibly in the form of a survey. Engagement should be encouraged on an international level, as well as knowledge sharing and understanding of the current scope of offsite and standardisation. These topics could be covered in education at an academic level, but also additionally in the provision of professional training in the form of short courses and in conference style events. These courses (potentially offered by academic institutions) would not be limited to industry professionals, but clients and industry institutions would also be encouraged to participate.

5.4.4 PUBLIC ENGAGEMENT

With regards to promoting these initiatives to the public, a commonly accepted vision needs to be agreed underpinning all future endeavours. It was evident that more needs to be done so that engineering would be promoted as a technology-based profession. This will also assist in addressing the skills shortage requirements, as well as helping to attract more women into engineering resulting in increased diversity. It would be beneficial if clients appointed communication champions and an industry day which will be set up to communicate findings within the wider industry.

Public engagement is necessary to communicate success and this could be achieved by creating a set of meaningful awards for offsite best practice, and possibly even by introducing a new category at the British Construction Industry Awards. Additionally, another idea put forward during the workshops was the creation of a virtual community space for each project to encourage the communication of long-term value gained by demonstrating the achieved benefits.

5.5 CONCLUSION

The overall aim of this research was to investigate the scope, constituent components and application of offsite construction in the Civil Engineering and Infrastructure (CE&I) sector. The research focused on the client needs and requirements in conjunction with the industry innovation initiatives and delivery strategies. As stated in Chapter 3, the data collection and analysed produced 5 papers. Table 5-1 provides a summary of how this thesis and the relevant publications satisfy the objectives set out in Chapter 2. Figure 3-3 in conjunction with Table 5-1 provide a clear link between methods used and conclusions drawn.
### Table 5-1 A brief summary of key findings in relation to research objectives and outputs

<table>
<thead>
<tr>
<th>Objective</th>
<th>Findings (summary)</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Review applications of Offsite in CE&amp;I sector.</td>
<td>- The industry has difficulty differentiating between offsite terms (e.g. standardisation, prefabrication, productisation, offsite, industrialised construction, factory thinking, etc).&lt;br&gt;- There is limited literature on offsite in CE&amp;I.&lt;br&gt;- Infrastructure sector is more risk averse and defines innovation differently to the building sector.&lt;br&gt;- Large programmes of works rather than small projects are key to realise offsite, in particular ‘linear’ type projects.&lt;br&gt;- The longevity of Infrastructure projects make it difficult to benchmark and quantify offsite benefits.</td>
<td>✔️ ✔️ ✔️ ✔️ ✔️</td>
</tr>
<tr>
<td>2. Evaluate the applications of Offsite in the sponsoring firm, its partners and clients.</td>
<td>- Each sub-sector has specific driver and barriers to offsite.&lt;br&gt;- Clients are pivotal for driving offsite.&lt;br&gt;- For holistic offsite implementation organisations need to have a top-down strategy.&lt;br&gt;- Offsite should be embedded within the project delivery governance processes.&lt;br&gt;- Offsite realisation should be linked directly to recruitment and training plans.&lt;br&gt;- The investment cycles in infrastructure clients hinders offsite realisation.</td>
<td>✔️ ✔️ ✔️ ✔️ ✔️</td>
</tr>
<tr>
<td>3. Analyse how BIM as a compulsory requirement for infrastructure projects will influence the realisation of Offsite.</td>
<td>- BIM can help enable offsite due to the encouragement to define the design earlier in the project lifecycle.&lt;br&gt;- BIM encourages the use of software that can identify repetition of components and therefore offer opportunities for offsite.&lt;br&gt;- BIM encourages the use of software that can simulate the construction sequence and therefore help enable offsite by reducing logistical challenges.&lt;br&gt;- BIM does not directly increase the offsite implementation</td>
<td>✔️ ✔️ ✔️</td>
</tr>
</tbody>
</table>
6 REFERENCES


Realising Offsite Construction in the Civil Engineering and Infrastructure Sector


Movement for Innovation (M4i) (2000a) “Partnering Success at South West Water” M4i, Watford, UK.


APPENDIX A INFRASTRUCTURE: THE ROLE OF THE APPROVALS PROCESS IN BOX JACKING PROJECTS

Reference:

Abstract:
In the UK civil engineering major roads and rail sectors, novel uses of offsite methods of construction have commonly been dictated by governmental body approval processes and Codes of Practice, predominantly the Highways Agency and Network Rail. Understanding the ways that such organisations influence the sector’s confidence regarding innovative construction methods and materials could help accelerate their development in the design and construction process, and hence maximise the possibilities of modernisation in the sector. By comparing two case studies of offsite precast concrete underbridge box-jacking, one as part of a government authority responsible for motorway contract and one with a government authority responsible for railway, the differences regarding prioritisation of acceptable risk are explored. The main drivers and constraints for offsite adoption and implementation are investigated and presented. Key challenges during the design and construction period of the projects are identified. These may focus on establishing effective communication between clients, designers, contractors and offsite suppliers/sub-contractors when implementing offsite, as well as understanding aspects of the physical integrity of assets that are dependent on the limitations of essential availability, disruption of usage or closure. By considering the differences in approach towards innovation and approval systems for the Governmental approval agencies responsible for motorways and railways, the parties involved can align their programmes of work and methods to help capacitate their clients’ needs, facilitating lean working processes throughout the procurement, design and construction stages.

Key words: box-jacking, civil engineering, innovation, lean, offsite.

Paper type: Conference Paper
Introduction and Background
Offsite techniques in buildings have seen a great development in the past decades. In infrastructure, although distinct benefits have been identified the transformation is proven lengthier. Many barriers have been identified including the inflexibility of the approval authorities to change and adjust. To address the occurring challenges two offsite case studies were analysed. Forming culverts and under bridges by reinforced concrete box-jacking may not be an innovative solution in itself but when an array of problems and limitations occur, this offsite solution could become extremely demanding and complicated to apply. The projects reviewed and compared as case studies in this paper have many similarities and one major difference. First, the same contractor, consultant and subcontractor were involved in both schemes. Secondly, the challenges faced were ground-breaking since in one of the projects the box was jacked into position under a live motorway (Figure 1) and the other was jacked under a railway line during a precise time-window of 101 hours. In both projects the margin for error was minimal, therefore very strict approval protocols had to be addressed in order to increase confidence so that the governmental approval agencies would authorise works underneath and around their assets.

Figure 1. RC Box-Jacking under a live motorway

The attitudes of the government approval agencies responsible for motorways and railways (road agency and railway agency) when considering adopting offsite, are compared to the practical challenges faced in these projects. Through this process the industry's beliefs and the asset management approval bodies' needs are analysed with the objective to identify the reasons for the diverse expectations when innovative construction collaborations take place. An additional objective of the paper is to underline the process of gaining confidence in an offsite solution while going through the common practice approval roots by identifying fundamental barriers and constrains. The specific aim of the paper is to assist an engineer working for a consultant, constructor or subcontractor to develop an understanding of the prioritisation process of the approval bodies when faced solutions that are not common practice. In conclusion, the overall aim is to contribute towards the maximization of the modernization of the sector via offsite implementation.
**Literature**

Innovation in construction has been a topic of thorough investigation. There have been a series of attempts to identify what drives and hinders innovation (Bossink 2004, Blayse and Manley 2004, Gann and Salter 1998, Koskela and Vrijhoef 2001). Bossink (2004) identifies the drivers of innovation in construction networks being focused upon environmental pressures, technological capability, knowledge exchange and boundary spanning. These drivers can also be sub-divided into management levels ‘intrafirm’, ‘interfirm’ and ‘transfirm’. This inductive approach allows for a general understanding of the issues from a theoretical perspective with an incorporation of the management aspect, which is unique. Furthermore, although many terms of innovation are generally defined, Bossink's paper lacks the definition of ‘construction network’ and the more practical research focuses predominantly upon the Dutch construction industry. Blayse and Manley (2004) approach is far more practical identifying six primary influences. These include clients and manufacturers, the structure of production, the relationship between individuals and firms within the industry and between the industry and external parties, procurement, regulations, as well as the nature and quality of organisational resources. Although these topics are thoroughly analysed the innovation strategy adopting the identified drivers in project work is lacking development. One of the points identified as a hindrance by Dulaimi et al (2002) was the lack of coordination between academia and industry when adopting research in projects, which was ignored by other literature. After having examined in detail how the standards and regulations affect innovation, Gann and Salter (1998) examined in detail how the standards and regulations affect innovation considering whether the performance based regulations hinder or drive novel methods of construction. Their analysis predominantly focuses on internal integration of business methods rather than the interaction of the firm with the approval body. Dubois and Gadde (2002) are accuse the government approval bodies of ‘hampering innovation’ with their negative influence. However, the responsibilities of the industry were not developed to the same extent.

Design and build work for a box-jacking project is not an uncommon practice. Therefore, it may be perceived as not particularly innovative. Nevertheless, according to Slaughter 1998 ‘innovation is the actual use of a nontrivial change and improvement in a process, product or system that is novel to the institution developing the change’. Furthermore, innovation can be ‘incremental’ or ‘modular’ (Slaughter 1998). The two projects reviewed faced strict time limitations and needed to overcome a series of extreme technical challenges referring to the alternative options considered and rejected (Allenby and Ropkins 2004, Ogborn et al. 2011). The technical issues and contractual processes were clearly mentioned in two journal publications that have governed the literature assessed in this research (Allenby and Ropkins 2004, Ogborn et al. 2011). Regarding the box-jacking schemes involving working under a live motorway, Allenby and Ropkins (2004) identify and analyse the detail of the mechanical system ADS used and the methodology employed to minimise disturbance to the running motorway above. The project that involved works under and around a railway may not have had to employ ADS system to such an extent (Ogborn et al 2011). The challenge was of a different manner because the available time window for works was 101 hours. Therefore, in the rail project there was no option of ‘freezing’ the works if a problem occurred dissimilarly to the motorway project. In addition to the journals above, there are a number of additional conference papers (Allenby and Ropkins 2006, 2001, Brunsden et al. 2003) that analyse different technical aspects of the box-jacking process but do not contribute any additional information.
Research Design and Methodology
The methodology employed is based on a combination of action research and grounded theory (Dawson 2009). This fuse of methodological approaches allowed the researcher to be flexible with novel issues appearing in conjunction to the data collection process and the ongoing literature review (Glaser and Strauss 1999).

Background Research
Prior to identifying the main aims and objectives of the research it was vital to conduct a primary background study through meetings, discussions and site visits. In addition, a secondary background study followed, where literature produced by industry facing magazines, construction and consultancy firms involved in box jacking projects has been included (Glaser and Strauss 1999).

Interviews
Ten people who worked on the box jacking projects were interviewed, representing a variety of seniority levels and roles within the industry and the approval agency. A combination of semi-structured and unstructured interview methods was employed to enable maximum input from the interviewees. The method has allowed data to be collected uniformly and enable comparability. Nevertheless, the interviews gave the researcher the opportunity to develop and analyse the parts of the project that needed to be considered in a more detailed way. In the first part of the interview, which was structured, the interviewer went through a set of questions (interview pro-forma) through which the necessary data was collected. During this process the interviewee gained a better understanding of the research undertaken and rapport/trust which was essential for the second part of the interview (Bryman 2008). At the second phase, the interview was unstructured, thus catering for an in-depth discussion over an area which through the first phase was identified as of additional value to the research. At the same time, in order to identify the most appropriate persons to interview a combination of purposive and snowball sampling (Dawson 2009) took place.

After the interview survey had been completed, two recent case studies were analysed. Both projects had the same contractor, consultant and subcontractor but working with a different governmental approval agency. One schemes involved jacking a box under a motorway and the other under a railway.

Data collection challenges
The predominant research tool employed was research interviews. There were significant challenges related to that process. One of the most common challenges occurring was bias. One of the case studies researched was more successful than the other, therefore some interviewees were distrustful, negative or answered keeping to an agenda. Others purposely derailed the discussion to cover areas that they had performed and completed well and they avoided others. More specifically, four main problems were faced in this research. Firstly, the participants’ defensive attitude due to the questions with regards to innovation within their organisation. Secondly, answering the questions following their organisation’s corporate policy rather than the factual information. Thirdly, a few participants would challenge the question rather than answering e.g. ‘you shouldn’t be asking that this way, if I were you I would ask this etc’. Finally, most interviewees did not use terms such as ‘offsite’ or ‘prefabrication’ to describe the box-jacking projects, fact which created the need to discuss the determination of terminology prior to discussing the projects.
Data analysis

The research methods and strategy would be considered as qualitative research since the qualitative continuum is applied as part of been an on-going data analysis process. A Comparative and a thematic analysis were employed to compare the interviewees’ responses amongst themselves and then against the approval authority in order to allow triangulation of data (Glaser and Strauss 1999).

Findings

Offsite as a term in box-jacking

During every interview with regards to the two box-jacking schemes under review, it was crucial to determine whether the people involved would consider the project as offsite construction. The majority of the participants were convinced that since the box was constructed on-site, the project could not fall into the offsite category. Furthermore, all the participants thought that offsite projects involve parts or complete structures being constructed offsite, in a protected environment and transported to the location of the building site. The phrase that was used was ‘offline construction’ where the ‘line’ was the motorway or the rail tracks (Figure 2). Therefore, ‘the box was built offline and pushed into position’. An additional interesting phrase that came up was ‘a movable structure’ or ‘a movable underbridge’ which includes a structure pre-constructed and then moved to its final position.

Figure 2 (Allenby and Ropkins 2004)
Adoption of offsite innovation - theoretically

The strategic approval authorities for railways and motorways involved in both schemes claim that they focus upon and promote innovation, especially as regards offsite because they appreciate its advantages. The benefit identified is the ability to have the asset in public use during construction and, if absolutely necessary, to have either a short term closure or a partial closure.

The road agency has got teams of specialists whose main priority is to assess and approve the usage of novel materials and techniques (HA). Furthermore, they argue that if a solution’s potential is recognised, they would work with the manufacturer to assist them through the testing and write codes/standards for their solutions. From their point of view, if the industry is not doing enough, they would aid and push for more innovative solutions (e.g. heat strengthening of steel parts). However, one has to clarify that the approval authorities are highly unlikely to do the testing, instead they would employ other consultants or contractors from the industry to assess the solution. Moreover, there are examples where the entire research on a product would be funded by the agency.

On the other hand, the roads agency acknowledged their conservatism, commenting that they ‘can’t afford to make mistakes because the public does not accept that therefore we are conservative by nature’. Nevertheless, they appear keen on employing novel construction solutions first at a ‘site trial’. That would include the method or the material being trialled on an A-road, first, and then on M-roads. There are many examples of experimental use of solutions on small projects in a side road or on a small council project. Secondly, the authority would review and monitor its performance by physically going back after a certain period of time or requesting data from the industrial parties involved. The focus would always be upon the cost-benefit risk analysis with main factors being the cost of savings against the potential damages if the system fails. One has to bear in mind that the costs, in case there is a failure, would predominantly occur due to the fact that assets are not kept available for use, therefore the approval authorities for motorways and railways would concentrate on materials and solutions that need minimum maintenance. When there is enough evidence that the product is adequate, then it will be considered for use in more important assets, ‘we wouldn’t place a new product on the M1, we would rather try it on smaller motorway first’

In more detail, having considered all the above, the approval authority's team that would have the responsibility of assessing the innovative solution, aiming to raise confidence, would ask the following questions: ‘Has the product been used before? - If it has been used before the team would review the specific conditions and circumstances aiming to assess if they match the requirements of the proposed scheme. If not then the following question would be raised asking ‘what tests have been in place?’ If the product has passed the testing criteria, the agency can proceed with greater confidence. Thirdly, if the product is so innovative that there are no common practice testing standards in place the agency would review practices from abroad and the tests employed there (e.g. SPS in Canada). Following that, the agency would work with the sub-contractor/manufactures in adopting such standards for the UK market.

From a major consultant's point of view, the industry seems to drive and push for innovation and the approval authorities due to their bureaucratic and tedious processes restrain the move towards offsite implementation and general innovation. One clear point uniformly made during
all interviews was that both national approval bodies, and especially the rail agency lack confidence and that leads to extremely conservative approaches. One participant quoted 'they love their way and they do not want to change'. Such views are completely rejected by the national approval bodies since they argued that if the solution is viable and financially beneficial, they would definitely be keen to approve it rapidly. Moreover, the road agency claim, as mentioned above, that there are cases where the agency would identify a solution employed abroad and introduce it to their projects without external industry pressures, funding the costs of testing to ensure that aligns with the agency's standards (HA).

**Adoption of offsite innovation - practically**

Through the case study analysis of the two box-jacking schemes, the above general statements can be assessed and can review whether when put in practice, the process would align with the theory.

**Decision Making**

The decision making process was very straightforward because both projects were based on constraint-driven design rather than on a cost-driven design (PB). The box-jacking solution was chosen because there was no other alternative solution according to the feasibility study. Box-jacking was not in itself a novel construction process but due to the circumstances and limitations in both schemes, the projects are considered ground-breaking. Arrays of alternative options considered are presented in the literature (Allenby and Ropkins 2004, Ogborn et al. 2011) but these ideas were developed on ‘the back of a fag packet’ (TR).

**Managing Risk**

In order to minimise the ‘project risk’ (JS) for months prior to commencing the design and build works, all parties involved including the approval agency had been engaged in discussions to determine exactly what the approval authority wanted as a final outcome and what their priorities were (TR, JS). The road agency, as a general statement, strongly recommends and identifies as of benefit to conduct thorough discussions prior to submitting departures or considering any novel methods of construction (HA). When the works began, ‘it seemed as if the previous efforts never took place’ (JS).

Technical risk and execution risk were unofficially divided into subcategories. Structural designs was not considered as a challenge but having unconventional soil conditions, such as contaminated ground, toxic carbons, the ‘geotechnical risk’ (JS) had to be analysed. Although the contractor takes a great part of the technical risk and execution risk, the design team claims to have conducted most of the risk assessments (JS). In addition, the client (local council) of the box-jacking under the railway tracks had identified a methodology for constructing this project (RJ, YM) and therefore the council had also done a major risk assessment (SO). To minimise the execution risk, the consultant had appointed a programme manager. A very detailed schedule ‘down to the nearest five minutes’ (PB) was created with contingency times on all activities and warning progress points. With regards to considering the financial risk, the consultants’ approach was to ‘think ahead and always take worst case scenario’.

**Discussion/Analysis**
Challenges in realising offsite innovation

The direct link to the approach of the government approval bodies towards innovative solutions was their financial contribution and necessity level of the scheme. As the box-jacking project, took place under railway tracks, the government strategic rail network operator had fractional direct financial involvement in the scheme by providing the 10.26% of the initial secured budget (Ogborn et al. 2011). The scheme took place because it was a necessity for the local council in order to eliminate the level crossing. The rail agency's single involvement was to ensure that the asset was available to the end user on time and all works were completed according to their regulations. In contrast road agency was the client and the approval authority for the project under a live motorway. The box-jacking was a necessity for the client/government body (Allenby and Ropkins 2004). Since, there were strict contractual agreements, the authority would approached every step of the approval process with direct interest in the costs, application and execution.

Challenges were faced in the approval of certain sections (TR, JS, OS, RJ, PB) of the box-jacking of the railway project because the government authority wanted a ‘gold-plated solution’ since they were not involved in direct contractual agreements. An example includes an approval form, which was reviewed and sent back and forth almost 20 times before having finalised. The industrial partners argued that this, ‘may have been due to personality driven differences or that someone from the contractors or consultants side was not willing to challenge the approval body enough’ (PB,TR). In defence to that the approval body claimed that ‘a proposal would get rejected because is badly written, not enough details or poor quality product’. Comparing the two options one can conclude that from the constructor’s or consultant’s viewpoint could assume a lack of confidence from the agency. In addition, ‘the client's requirements were met but the approval authority would hinder the development of the works that they were not directly involving the asset under their jurisdiction’ (SO).

The government approval authorities are clear that ‘with regards to structural aspects approval processes, raising confidence is not affected by the interpersonal relationship nor the success of previous projects. It has to do with the capacity of the material or the structure meeting our requirements’. In general, both the contractor and consultant have worked previously with the approval authorities prior to the box-jacking projects. More specifically, the same consortium of companies that worked on the motorway box-jacking project has already worked on the railway project (Allenby and Ropkins 2004, Ogborn et al. 2011). Acknowledging the above, in the railway box-jacking project, the approval body representative and the people involved in the construction consortium had not previously worked on such projects directly. The regulations from the governmental bodies are to be followed and the representative is there to ensure that that take place. Nevertheless, ‘one could do so by collaborating rather than directing’ (SO). In one of the case studies reviewed the approval body's representative followed the rules and contribute with ‘constructive criticism at times but he would not suggest a method just because he preferred or was familiar with it. We rather had to go back to him again and again with suggestions and keep getting rejected.’

SUMMARY AND CONCLUSION

One of the most important factors influencing the application and realization of innovation is the government approval bodies (Blayse and Manley 2004). They can be considered a driver or constrain depending on the approach one has followed so as to accomplishing increase of
confidence on potential projects. In order to ensure that the approval authority's representative is assured of the method/material proposed a strategy has to be inaugurated. This strategy should be a structured approach to confidence increase and is divided into two stages. The first barrier includes: ‘would the approval authority let the project commence?’. This is a challenge partly of a technical nature and partly of a design management nature. It is not sufficient to demonstrate detailed design and adequate technical knowledge of the solution. In addition to that, previous successful projects, good recommendation, highly credible individuals, good reputation, past effective collaborations on similar projects or other schemes would ensure reliability and therefore increase in confidence.

From the comparisons of the above box-jacking case studies it has been concluded that if the approval body is at the same time a client, there is more invested interest in the completion of the project, therefore consequently the approval authority/client is more keen in seeing it through to completion rather than just maintaining their assets available to the public. In contrast, if the client is not at the same time the approval body, then there may be barriers to overcome since the approval body may have the attitude 'what is it for us?'(PB). Nevertheless, it should be considered an advantage because ‘Approval body focuses on having the asset available to the end users not if the project around it has been completed. Therefore, when box-jacking takes place if we can assure the client that even if the box is not in place the rail/road would be in use they will be easier to convince.’(TR) At this stage of confidence building more applied and numerical evidence such as risk assessments, contingency planning and precise contingency methods, strict time planning and backup specialized machinery and equipment would increase confidence.

By understanding the main objectives of the approval bodies and act accordingly to convince them that your goals alight with theirs, the approval bodies could be considered as a driver rather than a constrain.

FUTURE RESEARCH

Contractual structure was shown to influence the approval process since the consultant in both cases was 'employed' by the contractor. Therefore, when submitting innovative designs, they would have to go through the contractor to reach the approval body (JS). Could aspects of the contractual structure be considered to drive or hinder adaptation of innovation? Moreover, the local community did not pose any obstruction which may not have been the case with innovative solutions in other projects. How does the local community influence innovation in the decision making of constrain-driven or cost-driven projects?

The key knowledge of an individual authorised by a government approval body to assess and update regulations has direct influence on innovating a specific sector (Gann et al 1998). The interpersonal relationship between the individuals representing the industry consortium and the approver representing the government authority could be the key factor to accelerate the introduction of innovation.

ACKNOWLEDGEMENTS

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APPENDIX B  REALISING OFFSITE CONSTRUCTION AND STANDARDIZATION WITHIN A LEADING UK INFRASTRUCTURE CONSULTANCY

Reference:

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

Paper type: Conference Paper
**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. 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. 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](image)

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 overlying 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.

**References**


APPENDIX C  ANALYZING THE NEED FOR OFFSITE CONSTRUCTION AND STANDARDIZATION IN THE UK WATER AND ENVIRONMENTAL MANAGEMENT SECTORS.

Reference:

Abstract:
The benefits of Offsite construction have been well documented. However, it is mainly the building sector that has been systematically employing such techniques. The construction industry is under extreme pressure to reduce cost and deliver more sustainable Infrastructure. This coupled with the high flood risk problems presented the past few years has increased the need of overall improvements. The strain is transferred to the water authorities that are considered as 'clients' for the construction industry supply chain. During the past year there has been a great interest from leading UK water and environmental management (W&EM) firms to develop and implement Offsite in their processes. The objectives for this initiative are to minimise cost, reduce disturbance to the public and manage the environmental impact in a more sustainable way. Recently, a number of new products have entered the water and wastewater market. Such solutions, in conjunction with the re-evaluation of decision making processes within the firms, create a fertile environment for Offsite implementation. The supply chain appears to reflect this need and is working collaboratively in order to provide competitive services to its clients. This paper reports and analyses this market inclination towards standardisation, modularisation and pre-assembly. Through an academic literature review, an analysis of corporate research and development strategies and an examination of specific solution, the reasons for inviting Offsite innovation are revealed. The findings indentify innovative procurement methods and strategic planning as the primary drivers for the uptake of standardisation and Offsite solutions in the sector.

Key words: Offsite construction, Water and Environmental Management, Client Organisations

Paper type: Conference Paper
Introduction

Many experts in industry and academia have seen Offsite as the future for the construction industry (DTI, 1998, Harty et al., 2007, Soetanto et al., 2006, Pan et al., 2007). There is significant research in identifying and analyzing drivers and barriers for Offsite (Goodier and Gibb, 2007, Blismas et al., 2005). The W&EM sector has a history of adopting best practice methods in the UK (Anglian Water, 2010, Southern Water, 2012). In this paper the importance of key government targets is described and reasons for realizing Offsite are established. Accordingly, focuses on what W&EM clients recognize as Offsite, their misconceptions and how they attempt to incorporate such solutions in their processes.

Background

With most of the water supply and sewage Infrastructure in the UK having been built in the nineteenth and early twentieth century, the network is in need of major improvement (HM Treasury, 2010b). During the past fifty years there has been a change in industry’s perception with regards to how Infrastructure assets should be managed. Nowadays, they are not seen as unconnected structures but rather an interconnected network that directly affects the operability of other assets (HM Treasury, 2010a). Extremely conservative estimations indicate that Britain will spend £45-50 billions in the W&EM sector by 2020. That is 10-11% of the total expenditure towards its Infrastructure (Helm et al., 2009). The current annual spend in the sector is £4 billion for 2010-2015 but is expected to increase as projects such as the Thames Tideway are commencing. The construction industry is under extreme pressure to reduce cost since according to the Eurostat Construction Price survey (Figure 1) the UK has the fourth highest Civil Engineering costs (Eurostat, 2009).

The government aims to reduce by 80% (Climate Change Act, 2008) the greenhouse gas emissions by 2050. The construction industry, especially the water and environmental management sector is under pressure to contribute to this goal by optimizing their processes to deliver low cost, low carbon footprint and good quality Infrastructure (Water UK, 2006). In addition, the sector has the main responsibility of safeguarding the UK Infrastructure from extreme weather events. The Meteorological (Met) Office and the Chartered Institute of Water and Environmental Management consider extreme weather phenomena and the socio-demographic challenges derived from climate changes to be the greatest risk of critical Infrastructure. Since Peter Hansford took over as chief construction advisor the pressure for not only value for money but also value for carbon has increased (Hansford, 2011).

There was been an initiative to improve the regulatory regime for the water sector in order to assist with the current industry demands. The Council for Science and Technology (CTS) instigated changes in mechanisms aiming to reward innovation through new technologies resulting in stimulating the supply chain to develop more sustainable and efficient solutions. Currently the development of innovative solutions in hindered by a five-year regulatory review period (HM Treasury, 2010c). Furthermore, the CST’s report urges for a reward process for the water and sewerage firms that commit investment for developing long-term sustainable, low-carbon solutions (CST, 2009). The above recommendations also concur with the findings from the report of the Institution of Civil Engineers (ICE, 2009, ICE, 2011).
Methodology

The research method employed is based on a combination of quantitative and qualitative analysis (Dawson 2009). The reasoning of the research is inductive (Fellows and Liu, 1997). This blend of methodological approaches allowed the researcher to be flexible with the emergent data collection process and ongoing literature review (Glaser and Strauss 1999). Background research took place in order to identify similar projects in the past. Internal reports were reviewed including bids, project descriptions and other relevant documents such as industry facing publications. In addition, academic publications such as conference and journal papers were reviewed. Although the refereed publications were very limited, lessons learned from other industries and sectors where deemed relevant for the field under investigation.

The raw data collected were based on three case studies. The case studies are based on three water and environmental management firms’ interest and demand for increase in standardisation and Offsite solutions throughout their works. The analysis is based on Eisenhardt’s (1989) approach to building theory from case study research. The potential of such solutions was identified through a series of request to a major UK consultancy. This reoccurring pattern was discussed with the three client directors. A combination of semi-structured and unstructured interview method was employed to enable maximum input from the interviewees whilst allowing data to be collected uniformly (Glaser and Strauss 1999). The interviews were recorded and transcribed. A group discussion followed. The participants included the three client directors, three project managers of major projects and the global innovation director. Driver and barriers and the potential of Offsite solutions in W&EM sector were discussed.

There were significant challenges related to the data collection process. The Offsite construction request that are analysed by this paper were made in different geographical locations and for projects under complex frameworks which made the comparability challenging. Due to confidentiality reasons and competitiveness many reports were not accessible. The reports obtained used different terminology for Offsite solutions such as ‘modularised units’, ‘the prefabricated elements’, etc. The understanding of the term Offsite was also confused by many participants during the interview process as ‘lean construction methods’ or ‘just-in-time management methods’.
Discussion

Demanding and informed clients are considered a driver for innovation (Gibb and Isack, 2001). The majority of practitioners in the construction industry are familiar with the current capabilities, advantages and disadvantages of Offsite (Goodier and Gibb, 2007). In the W&EM sector, client organizations at a corporate level comprehend the benefits and drawbacks of Offsite. Nevertheless, at a practitioner level there are limited examples of engineers that still see Offsite as solely a ‘one fits all’ standardize solution. This concurs with findings from Goodier and Gibb (2007), although their research focus predominantly in the building sector (e.g. housing, offices and hospitals). Offsite in the W&EM are not considered innovative. Offsite solutions such as precast concrete have been employed in the sector and are considered common practice (Vernikos et al, 2012). W&EM clients, are taking a holistic and inclusive evaluation of Offsite attempting to incorporate standardization and Offsite in their processes for their projects.

Drivers

Time, quality and cost are considered the greatest advantages of Offsite by the literature (Gibb and Isack, 2001, Goodier and Gibb, 2007, Venables et al, 2004). The main advantages of Offsite identified for the W&EM sector are cost reduction, lower environmental impact and reduction of disturbance to the public due to minimisation of onsite works.

The clients consider that the supply chain could deliver its program far more efficiently if standard designs were used that could be ‘pulled off the shelf’ depending on the type of ‘frontage’ required. The participant in the research had difficulty in differentiating between Offsite construction and standardization. It is common for Infrastructure projects to be considered as bespoke, nevertheless clients believe that creating standardised designs may not have immediate effect in savings but result in cost reduction in future projects. This agrees with findings in other sectors (Gibb and Isack, 2001). Client organizations, mainly due to governmental pressure claim that cost is not always a governing factor in their decision making but environmental impact. In practice, evidence dismiss this argument. This comes as no surprise as in the past non-momentary benefits have been ‘merely alluded to, or disregarded’ (Blismas et al, 2006).

The sustainability aspect of Offsite construction has been seen by many as a driver (Blismas et al, 2005, Goodier and Gibb, 2007). The main areas identified include less waste, noise and disturbance (Blismas et al, 2005). These reductions are resulting due to the closely monitored manufacturing process in factory-like conditions although more research in the areas is needed (Gibb, 2001). Sustainability issues may incorporate environmental, social, economical aspects. The waste of materials is a common problem in the construction industry. Offsite construction has the potential to firstly reduce the waste because the design focuses of manufactured elements therefore ‘can reduce programmed wastage’ (DTI, 1998). Notwithstanding, recent research has shown that the environmental benefits of Offsite construction are not considered as of great importance (Larsson and Simmonson, 2012). In the W&EM sector the reduction in environmental impact is related to the minimisation of rework but also because it is expected that through Offsite solution the design will be more efficient. Some clients claim that in their product based Water Treatment Works, by using 70% Offsite construction they achieve 60% reduction in embodied carbon.

Barriers
W&EM clients have tried to address many of the documented barriers to standardization (CIRIA, 2001, Pasquire and Gibb, 2002). The clients ‘route to continues improvement’ loosely follows CIRIA Client’s Guide and Tool Kit (2001) to optimize benefits from standardization and pre-assembly. The clients claim to have developed a process where a product is developed, followed by standard work manual (e.g. Midi Submersible Pumping Station, Product installation Guide). Approval processes in Infrastructure have acted as a barrier to realize Offsite (Vernikos et al., 2011) and clients have been resistant to change due to negative image of Offsite in the past (Venables et al., 2004). Industry organizations (e.g. BuildOffsite) have been promoting certification for Offsite products. In the building sector according to results from the prOSPa survey (Goodier and Gibb, 2007) the majority of suppliers have their products certified. This is not common for Offsite solutions in Infrastructure as they are seen as ‘one off’ solutions. Recently the adoption of volumetric (e.g. pumping stations pods, adjustable manholes) and non-volumetric (e.g. treatment tanks) solutions in the W&EM sector has flourished. Such innovative solutions were adopted by the sector after trial-construction, trial-assembly and conducting full size scales testing. This increased the confidence of the client without the need of certification.

**Managing the Supply Chain**

Latham (1994) may not have been the first to advocate partnership and collaboration as a mean to drive improvements and innovations but he was the one that captured the construction industry’s attention. Four years later Egan (DTI, 1998) continued to promote supply chain collaboration drawing comparisons with the development of modularization and standardization in the USA as a mean to reduce cost. In the early 2000, following the recommendations of the two reports above the W&EM sectors attempted a series of projects under the Movement for Innovation (M4i, 2000a, M4i, 2000b). These case studies demonstrated improvements through collaboration without yet incorporating much Offsite to their processes.

In traditional construction the approach is linear, starting with the feasibility, design, tender, construction, handover and operation. Inherently this approach is insufficient in implementing innovation as benefits from planning, novel materials and solutions are not evident in the design face unless the contractors or suppliers are invited in the early stages of the process. Another approach to construction is under a design-and-build contract. This ensures greater involvement from the contractors but challenges occur when having bid on low margins the contractor seeks to increase profit from higher margins on any later change through the project (MacKenzie and Tuckwood, 2012).

Gibb and Isack (2001) discuss the clients’ belief that the fragmentation of the supply chain poses challenges for Offsite. W&EM clients have progressively attempted to consolidate the supply chain (Anglian Water, 2012) through ‘delivery partnerships’. This partnering arrangement model is aiming to increase collaborations throughout the supply chain. The collaboration encourages the understanding of all parties’ needs at the early stages of the process. This model is approaching construction at a program-by-program rather than project-by-project basis. Similar examples have been seen in the building sector with great success. BAA’s Terminal 5 is a prime example (Pryke, 2009). This comes with much delay as Offsite construction coupled with supply chain partnerships were identified as key to improve construction processes by Egan in 1998 (DTI, 1998).
The HM Treasury report (2012) on environmental networks states that by smoothing the investment cycles in the W&EM sector could provide a better environment for innovation to flourish. The current investment process makes the clients and therefore the supply chain to adopt a project-by-project approach to solutions rather than a holistic and systemic approach. The supply chain claims that cyclical investment has been a hindrance to innovation and overall cost reduction so the past years and although this reports is addressing the problem more action should be taken. In the beginning of 2013 it is expected that a government report would be available focusing on new Infrastructure procurement routes that will address further the issue of cyclical investment (Water UK, 2012).

**Conclusions**

W&EM clients have been driving Offsite solutions by creating a platform for ‘product-based delivery’ and ‘product integration’. W&EM clients claim that this can be achieved by creating a ‘product catalogues’ alongside a knowledge management system that ensures continuous improvement. Nevertheless, it is admitted that this is not the standard work process yet but there are few ‘best practice examples’. The success of the increasing usage of Offsite in the W&EM sector is yet to be confirmed as most data currently available are from anecdotal evidence. Significant steps have been made to homogenize the supply chain by improving the procurement processes. Modular Offsite solutions such as pre-assembled pumping stations are a great example of cross-sector fertilization of innovation as they can be compared with solutions (e.g. multiple service distribution modules) for the building sector.

There are still considerable issues when the program-by-program model is utilized. There are examples of linear Infrastructure assets such as river embankment that are not monitored accurately. The large amount of data on each segment’s location, type of solutions used, and condition hinder the utilization of Offsite and standardization. Despite the current technological capabilities available (e.g. GIS, BIM) most data are still in reports or paper format which does not allow identification of opportunities for Offsite.

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APPENDIX D  IMPLEMENTING AN OFFSITE CONSTRUCTION STRATEGY: A UK CONTRACTING ORGANISATION CASE STUDY.

Reference:

Abstract:
Many United Kingdom (UK) contractors only consider offering offsite solutions on a bespoke project-by-project basis, with very few having immediate plans for integrating fully offsite manufacturing as part of their core business strategy. Limited literature exists regarding how a major UK contractor could achieve such a strategic offsite capability, as this capability is usually referred to as an out-sourced, sub-contracted activity. The concept of a major contractor providing its own capability and completing large scale infrastructure projects using offsite construction (OSC) methods is not common in the UK, although the concept is less rare in certain other countries, such as Australia. The aim of this paper is to determine the benefits that OSC can offer for UK contractors and to investigate how an offsite strategy can be implemented in practice. Semi-structured interviews were conducted with a major UK contractor, transcribed, and thematically analysed to determine how effectively the offsite strategy and methods were being implemented at different levels within the contractor’s operations. The potential attractiveness and future of offsite for major UK contractors is discussed. The paper concludes with three recommendations for contractors considering the development of offsite capability. First, commitment from senior leadership at a strategic level, second, clear communication to all level through the firm and third, investment in innovation.

Keywords: Case Study, Contractors, Infrastructure, Offsite, Prefabrication, Strategy

Paper type: Conference Paper
INTRODUCTION

Significant research into the drivers and barriers to OSC has been undertaken (Nadim and Goulding, 2010; McKay, 2010; Blismas et al., 2005; Gibb, 2001; Goodier and Gibb, 2005a; Goodier and Gibb, 2007). Attempts to establish similarities in approach between construction and manufacturing companies have been made, and it has been commonly suggested that OSC should utilise manufacturing techniques similar to those used in automotive manufacturing (Egan, 1998; Crane et al., 2002; Constructing Excellence, 2009). Currently, the UK Government is looking into offsite as an option for cheaper, more affordable housing (Miles and Whitehouse, 2013). There is also significant knowledge regarding the principles behind manufacturing and offsite (Gann, 1996; Pan and Arif, 2011; Gann, 2010). There is little literature, however, on how a major construction contractor could begin to achieve its own in-house offsite capability, other than simply taking advantage of a project-specific opportunity. The process is usually referred to as an out-sourced, sub-contracted activity (Yorkon, 2013). The idea of a major contractor providing its own capability while completing large scale infrastructure projects for clients using OSC is rarely discussed. “The question remains, what construction companies have to be mindful of, when going for manufactured construction?”(Pan and Arif, 2011). The aim of the research is to identify key measures that will enable a contractor to successfully obtain an offsite capability.

Manufacture and Construction

The performance of the UK construction industry has been frequently debated, with the industry's perceived poor performance commonly cited (Latham, 1994; Egan, 1998; Crane et al., 2002; Constructing Excellence, 2009). Specifically, the efficiency of construction activities is frequently questioned, particularly by Egan (1998), who thought that "within five years, the construction industry should deliver its products to its customers in the same way as the best consumer-led manufacturing and service industries. To achieve the dramatic increases in efficiency and quality that are both possible and necessary we must all rethink construction". These reports have increased the profile of offsite and encouraged debate (Pan and Arif, 2011; Constructing Excellence, 2009).

OSC could be described as a manufacturing process used within construction by virtue of its production process, prior to transportation and installation. Business leaders in manufacturing are often cited as championing standardisation and mass production (Pan and Arif, 2011). Increased standardisation of components in buildings can result in fewer defects, higher quality and a more reliable rate of production depended on less fluctuation in construction programmes of projects (Egan, 1998; Gibb and Isack, 2003). As a result of Henry Ford’s vision, mass production became “almost synonymous to manufacture” (Crowley, 1998). Pan and Arif (2011) claim that customised production could not offer benefits, such as economies of scale, that mass production provided. However, it is recognised that mass production is not necessarily an aim for all OSC products, particularly with infrastructure projects which are often "prototype" projects - one-off construction of a particular size, span, skew or other trait.

Egan (1998) based his recommendations for improvement on the techniques of automotive manufacturers. This raised the question of whether the construction industry could adopt a similar approach. In the automotive industry, “products” cover a wide range of vehicle sizes and types. All production is undertaken in controlled environments and the basic "model" is
standardised with only matters of detail being varied. Strategic plans for manufacture are made across cycles of several years. Planning considers the whole life-cycle of many of the lines launched within this period. Automotive manufacturers aim to predict the expected sales of prospective product releases before planning for production capability and resourcing (Fleischmann et al., 2006). Buildings however, have a longer life-cycle than cars and higher unit production costs. This makes sales planning over such lengthy periods challenging. In construction the "product" provided is significantly different with regards to output (Gann, 1996; Pan and Arif, 2011). When compared to many other manufactured "products", housing and buildings have complex components and are of a much larger scale, and with greater expected durability (Pan and Arif, 2011). Pan and Arif (2011) discuss “the logic of mutual learning between construction and manufacturing is perceived to, and should, be embedded in the many attempts to address their relations”.

**BACKGROUND**

**The UK OSC market**

Various attempts have been made to quantify the UK OSC market (Goodier and Gibb, 2005b; Goodier and Gibb, 2007). The size of the UK "offsite fabrication" market was estimated to be worth £800.9m in 2002 (Samuelsson et al., 2003), which is 1.7% of new construction (£47.137bn in 2002). Goodier and Gibb (2007) estimated the total value of the OSC market in the UK in 2004 to be £2.2bn, with the total value of the UK construction sector being £106.8bn. The proportion of the UK offsite market was therefore 2.1% and was predicted to reach approximately £4bn by 2009. BuildOffsite predicted a market of £6bn by 2009 (Goodier and Gibb, 2007). Taylor (2010) obtained financial accounts for 245 companies operating within the UK OSC sector. From the market’s turnovers and profits, he estimated that the value of the OSC would contribute between 6% and 7% of construction output and the value predicted for 2013 was £4.8bn (Taylor, 2010). This 2013 prediction considered the recession of 2008-09 whereas Goodier and Gibb's (2007) did not. Nadim and Goulding (2010) explained that the majority of growth would be in new buildings rather than refurbishment work and that the UK was ready to “embrace offsite production”. At that time, two thirds of respondents felt the UK was ready for such an uptake.

Historically, in the UK profitability for contractors has been low, with large turnovers required to generate significant economic stability. The Government’s Department for Business and Innovation and Skills (2011) provided data on Key Performance Indicators (KPI’s) across the whole construction industry which demonstrated further evidence of this decline in profitability. These statistics supported by the Construction Excellence report (2009) emphasise that the construction industry getting by without much innovation before the recession. The industry’s productivity was clearly dropping, whilst profits were rising and staying high. Only once profits began dropping, productivity within the industry began to increase dramatically. This was an economically unstable practice and required "significant improvement" (Constructing Excellence, 2009).

**Research and Development (R&D) in the UK construction industry**

R&D in the construction industry has been frequently debated (Hampson and Brandon, 2004). The amount of money spent on R&D in the UK construction industry is insufficient to lead to performance improvements (Dulaimi et al., 2002). Sir John Fairclough’s 2002 report concluded that a “modern, efficient, high quality construction industry” would benefit society. In order to
achieve this, he recommended innovation driven by R&D activities (Fairclough, 2002; Kulatunga et al., 2007 and 2009). Macmillan (2002) also argued that R&D activities were important in improving the performance of the UK construction industry. R&D has been credited with the ability to influence and encourage best practice within the industry (Barrett, 2007). As with any exploratory activity however, there are risks attached to undertaking R&D activities (Van Rooij, 2008; Mitchell and Hamilton, 2007). Kulatunga et al. (2009) discuss that R&D activities may not always deliver obvious benefits or generate large profits, but there is a possibility that construction organisations could benefit in the long run by considering less obvious innovations and changes. They argue that effective management to minimise the risks of R&D was required in industry, as opposed to “rejecting R&D altogether”.

The need for more R&D, innovation and OSC is discussed by the literature, however innovation is risky, and offsite requires investment in manufacturing. Hence, if a major contractor chooses to invest, aside of the technical difficulties, it is critical to methodically review the company’s culture aiming to embrace OSC within its normal business processes.

RESEARCH METHOD

Qualitative case study analysis based predominantly on the Eisenhardt (1986) approach was employed, focusing on capturing the dynamic research potential of offsite innovation in an organisation by using multiple levels of analysis within a single study. A literature review was firstly undertaken, including content analysis of industry reports (i.e. annual reports, company websites and business strategies). After reviewing the innovation strategies of the six leading UK contractors one was chosen to be investigated due to its company strategy being strongly aligned towards offsite innovation. Nine members of staff were interviewed, representing a variety of seniority levels and roles within the firm, from site civil engineers, to construction managers, to senior commercial managers. This sample enabled comparisons between the opinions of technical and commercially orientated staff’s views of the firm’s innovation and offsite strategy.

Semi-structured interviews were employed to enable maximum input from the interviewees whilst allowing data to be collected uniformly (Glaser and Strauss, 1999). The first phase of the interview was structured using an interview pro-forma, followed by more in-depth discussions on key points identified by the interviewee. In order to identify the most appropriate people to interview a combination of purposive and "snowball sampling" (Dawson, 2009) was conducted. All interviews were recorded and transcribed. Thematic analysis was employed to compare the interviewees' responses amongst themselves and also against their firms’ innovation strategy and the literature, in order to allow triangulation of the data (Glaser and Strauss, 1999).

ANALYSIS AND FINDINGS

Although OSC was mentioned by four of the six contractors in their annual reports as being a competitive advantage for the firm (Table 1), it was evident from their strategy that Firm D was making the most significant steps in achieving its own offsite capability. The six documents reviewed may not cover all aspects of the firms' commitment to construction innovation and OSC nevertheless the research considers them valid sources of qualitative data as they are the formal and official strategy. Other firms were more unclear as to how they were investing in and developing offsite, if it was mentioned at all. Most commonly it was through specialist suppliers on a project-by-project basis.
Table 1: Summary of the leading contractors’ competitive advantage propositions according to their strategy or annual reports from 2011 and 2012

<table>
<thead>
<tr>
<th>Competitive advantage stated in company literature</th>
<th>Contractors</th>
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<tbody>
<tr>
<td></td>
<td>A  B  C  D  E  F</td>
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<tr>
<td>Sustainability</td>
<td>X  X  X</td>
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<tr>
<td>Quality</td>
<td>X  X  X</td>
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<tr>
<td>BIM</td>
<td>X  X</td>
</tr>
<tr>
<td>Culture</td>
<td>X  X</td>
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<tr>
<td>More comprehensive capabilities than competition</td>
<td>X  X</td>
</tr>
<tr>
<td>Asset Management</td>
<td>X</td>
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<tr>
<td>While-life cycle services</td>
<td>X  X  X</td>
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<tr>
<td>OSC</td>
<td>X  X  X</td>
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<tr>
<td>Supply chain engagement</td>
<td>X  X</td>
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**Offsite strategy implementation in firm D**

The analysis aimed to investigate whether the employees of firm D were aware of and actively implementing elements of the business strategy put in place to increase the usage of OSC throughout the organisation. Various benefits of offsite were presented in their company strategy; six aspects of the strategy were considered - 3 were strategic objectives (offsite as core process, commercial benefits and cost savings) and 3 were benefits on projects (quality, safety and sustainability improvements) and these were used for the interviews.

In terms of the benefits highlighted in the firm’s annual review, business strategy and discussed with the interviewees, 7 of the 9 respondents felt that offsite was giving the company a slim "edge" over the competition. 6 respondents felt offsite provided quality improvements. With regards to safety, 6 respondents felt that safety improvements were provided by offsite. The greatest disagreement was when respondents were asked if they felt offsite created cost savings for their firm, with 4 positive, 2 negative and 3 with divided opinions. The more senior engineers explained that the upfront costs for projects could be offset by the reduction in site labour and programme duration. Some stated that they "knew" the firm was currently subsidising its offsite activities, but believed that in the long-term cost savings would materialise and hence increase profit margins. The current main saving cited was a reduction in material deliveries in comparison with in-situ construction, leading to far less deliveries, as well as a reduced carbon footprint, depending on the size of the item.

All 9 interviewees claimed that quality improvements were achieved through the usage of offsite. However, two did express their concern regarding the achievable quality improvements as they experienced quality issues and defects on some projects. The defects did not occur during the manufacturing phase but predominately during the delivery and installation process. This could be attributed to lack of experience in offsite and installation of some of the site staff. Two respondents (who had both operated in technical on-site roles) provided examples of
Effective offsite implementation. One explained that offsite usage provided “a different set of challenges”, supporting Nadim and Goudling’s (2010) findings on the difficulties in utilising offsite solutions. Sizing issues with the offsite deliveries from the manufacturing facility were mentioned and it was explained that it is very difficult to adjust to incorrectly provided or late changes in dimensions, which could be managed more easily with in-situ techniques. Effective management of the "organic" or "live" environment of construction sites and contractor activities was also highlighted as very important. Drawing changes were also sometimes being made after offsite components had been manufactured and dispatched for the site, causing fabrication problems. This is supported by the literature as a lack of flexibility in offsite designs and as a barrier to greater uptake (Nadim and Goulding, 2010; Goodier and Gibb, 2007). A respondent also stated that “information management is very important for successful usage of offsite.”

Sustainability benefits due to offsite were mentioned by only 4 interviewees. Most interviewees understood sustainability solely as having environmental impact and dismissed or didn't mention the economical and social aspects. Nevertheless, some raised the concern that the adaptation of offsite at a national scale may result in the reduction of labouring jobs and reduced income for many construction operatives. In addition, all of the respondents except one felt offsite usage provided savings in the construction programme. Customer satisfaction was only cited by two interviewees as a benefit for offsite, both of whom were from a commercial background. This could suggest engineering staff are more focused on the benefits to site operations and project delivery, whilst commercial staff are better able to appreciate client driven aspects.

**Issues affecting successful Offsite**

The most commonly mentioned barrier was the up-front cost to set up a manufacturing facility, particularly with the current UK economic circumstances. This was mentioned by all respondents to differing degrees. An additional barrier was the availability of good external specialist suppliers. By using only one source of manufacture, there was a high risk that problems at the source would affect all of the supplied projects. Strong management of information and quality within the manufacturing facility is needed to combat this. It was explained that in their experience, external suppliers cost the same as if the firm produced its own offsite components. The initial cost to develop offsite capabilities can be seen as unnecessary if the production costs are not cheaper in the long run, but it is worth noting, as stated by few of the interviewees that when components are self-produced, money is being kept within the contractor’s business, which can have positive impacts on cash flow and company turnover. Additionally, offsite was sometimes seen as a potential barrier to winning work, with the firm's offsite strategy encouraging and promoting its use where appropriate. Care therefore had to be taken to ensure that offsite was not employed where an in-situ or bespoke solutions would be more appropriate. Further barriers also included geographical location, as some projects may be too far for delivering components. The time delay for successful training of a manufacturing workforce must also be considered, and was cited by two respondents. The case study contractor is a privately owned construction company, whilst the contractors with similar levels of turnover and delivering similar projects were publicly owned by shareholders. The requirement to satisfy shareholders was seen to be a barrier to significantly changing a companies’ business model and strategy in order to adopt a more offsite capability. It was felt that the nature of the construction industry, with companies currently taking work at very low profit margins, was leading to more short-sighted planning and business decisions rather than
forward thinking innovations, supporting the Nadim and Goulding (2010) survey of construction companies. Many felt that smaller companies did not have the necessary volume of work to make offsite use economically viable.

**Implementing the Offsite Strategy**

It is evident via the interviews and the company strategy that the firm is committed to supporting the implementation of offsite via various methods. These include a company intranet, which provides basic information and raises awareness of best proactive examples through an online catalogue of the offsite components available to site teams, and a graduate development programme that focuses on educating the inexperienced engineers with regards to the importance of offsite and its application. The company holds two "road shows" per year, where business leaders and directors communicate with all employees, with the aim of motivating the staff and keeping them focused on the firm’s offsite targets. This provides a structured way for project leaders to communicate to site teams particular offsite solutions that may be best for individual projects.

When asked if the aim of the firm's strategy was achievable, the general response was positive, but with conditions. One third of the respondents were entirely sure that the aim could be achieved. Many issues with over-expectation were provided by the other 6 respondents. The suitability of all project types was mentioned; not all projects can use offsite solutions, such as refurbishment contracts. Examples were provided where the site team found the utilisation of offsite solutions on refurbishment projects to be challenging, particularly where assembling prefabricated components indoors was not possible. This supports Blismas et al.’s conclusions (2005) that projects should be considered individually before offsite is recommended, to ensure suitability. Nadim and Goulding (2010) also predicted that there would be a rise in offsite usage for construction projects, but not refurbishment projects. Three respondents felt that achieving the strategic offsite implementation aim by 2020 was unrealistic, with one respondent remarking, “it could be achieved perhaps, but perhaps the business is pushing a little too hard for it.”

**DISCUSSION**

The research showed that the innovation strategy employed by the case study firm was targeting many of the offsite benefits cited in literature and the strategy claimed that the vast majority were being realised on projects. Although all the companies in Table 1 mentioned “innovation” multiple times in their annual reports and strategies, investing in R&D was not mentioned in any, which is crucial for increasing productivity (Latham, 1994; Egan, 1998; Fairclough, 2002). The UK government has been prompting improvements in the industry’s performance and profitability for many years, suggesting OSC as a possible solution (Latham, 1994; Egan, 1998; Crane et al., 2002; Constructing Excellence, 2009). According to the interviewees, the costs of providing manufactured solutions are very similar to using in-situ solutions. Nevertheless, the firm’s strategy is hoping to have savings due to reductions in wasted materials, labour requirements on site and shorter programmes. A major contractor providing its own offsite manufacturing capability is an innovation to the traditional contractor business model. However, the techniques utilised are not all completely new and there are many established companies who have been providing offsite solutions for many years. A risk-averse culture is
resistant to change (Kulatunga et al., 2009), but effective management can minimise the risks of R&D and will provide far greater benefits for industry than simply rejecting R&D altogether. Although is the firm has a precise strategy with targets for offsite, the respondents indicated that offsite is used on a project-by-project basis and wherever it is seen as appropriate. It was made clear that there are no formal measures in place to force offsite upon project teams, supporting Blismas et al.’s (2005) advice on considering projects individually for OSC suitability. Only two of the respondents could quote the firm’s set targets for offsite on projects. All respondents felt that having a robust offsite strategy will provide the firm with a future commercial advantage in the UK construction market place. However, there was some scepticism with regards to the return on investment as the cost for providing such capability will take “a long time to pay off”. The firm’s annual review explained that the offsite agenda is currently being subsidised within the business, and that on-going R&D was required, with £7m being spent in 2011-12. In the short-term, offsite capability may not be providing the firm with a financial advantage. But when work-winning for future projects and leading the market place in the future, the respondents believed that there may be significant benefits from differentiating their operating model from the more traditional one (and from others). Most believed that this speciality of the firm allows them to undertake projects that other competitors may not have the capacity or reputation to undertake. However, concerns were expressed as to how clients and local people would react to decreased employment opportunities as a result of reducing labour on site.

With regards to employee buy-in, the respondents were aware of the firm’s dedication to an offsite agenda and agreed it would be the future for the business. The aim to achieve offsite capability was introduced in the firm’s 2007 annual review, suggesting that on-going planning was taking place. Technologically, a company taking on the entire responsibility for manufacture and installation without specialists is seen as a great innovation (Teece, 2010). All interviewees were confident that the firm had the resources in place to achieve its offsite goals, but not by 2020 (as per the firm’s aim). It was also made clear that there were two sides to the issue, as there may be an advantage to some projects but on the contrary, the firm may alienate itself from other potential projects where offsite is not suitable. There was a general belief amongst all the respondents that competitor firms were waiting to see whether this offsite initiative would be successful. Indeed, successful business models are usually copied, ultimately giving rise to many competitors within single industries (Teece, 2010).

Bessant and Tidd (2007) claim that, “the survival and growth question poses a problem for established players but a huge opportunity for newcomers to rewrite the rules of the game”. OSC may offer a construction contractor significant commercial success if they are able to implement it and provide it for clients in an attractive way. Innovation is also credited to larger organisations in most cases due to their ability to invest in R&D and create new ideas and concepts to bring it to the marketplace (Mann and Chan, 2011).

**CONCLUSIONS**

Three main strategic measures appear to be required in order for a major contractor to successfully obtain an offsite capability. Firstly, a leadership team who are committed to achieving innovation through OSC, exhibited in this case through the development of an in-house consultancy cross-cutting the organisation, with an emphasis on innovation. Secondly, clear communication is needed to employees at all levels regarding the intention to use OSC
e.g. communication best practice examples from project leaders to site teams on individual projects and training of graduates who may go on to become future site managers or business leaders. This commitment to communicate the importance of offsite was also exhibited here through the firm’s online intranet and in-house catalogue of available offsite components. Thirdly, it must show commitment through investment in R&D and a clear business strategy.

**FURTHER RESEARCH**

A similar interview based case study research should be undertaken with employees of other major contractors to gauge their thoughts on OSC and compare perceptions. A detailed cost-benefit analysis should take place on the construction and operation of an Offsite manufacturing facility to provide quantitative data for future business cases for Offsite manufacturing capabilities. Contractual agreements should also be investigated as they may act as a hidden barrier to OSC. Finally, an undated investigation into client perceptions of OSC will provide clarity on whether the UK construction is increasing the usage of OSC as dated literature claims.

**REFERENCES**


APPENDIX E  INVESTIGATION INTO HOW BUILDING INFORMATION MODELLING AFFECTS THE REALISATION OF OFFSITE CONSTRUCTION

Reference:

Abstract:
In 2011, the UK Government mandated that all construction projects (buildings and infrastructure) that they procured would be undertaken within a 3-D BIM (Building Information Model) environment, by March 2016. This has caused both construction procurers and providers to embark on a journey towards universal BIM adoption, including the integration of BIM within a revised construction process. In addition, offsite construction has seen significant development in the building sector in the past decade; however in infrastructure, offsite exploitation has been more limited. This paper presents findings from research into how innovation initiatives such as BIM and offsite can and need to be considered together, thus allowing leaner design, a greater integration of lifetime project data and more novel technical solutions. Key themes that emerged from the thematic analysis of the interviews show the importance of configuration and interface management; information data flow; project management and delivery; procurement and contracts. The analysis outlines the benefits of utilising offsite within a BIM environment, the challenges currently facing the supply chain, and recommendations are made as to how best to implement the emergent benefits.

Key words: Infrastructure, Building Information Modelling, Offsite Construction

Paper type: Conference Paper
INTRODUCTION

Improving efficiency in construction has been on the agenda of the UK Government and industry for many years (Wolstenholme, 2009); various attempts and initiatives have been documented, addressing different aspects of the construction industry (Figure 1). Recent initiatives – including BIM, lean construction and offsite – aim to reduce costs through improved resources and enhanced data management (Vernikos et al, 2011) with BIM becoming increasingly applied within the UK construction industry in recent years. BIM implementation is occurring via a ‘push–pull’ process with BIM slowly embedded in various forms and methods in many current construction projects (National BIM Report, 2013).

The UK Government wants to achieve a 20% savings in construction costs and aims to implement BIM in all Government construction procurement contracts by 2016 (Morrell, 2011) in the expectation it will contribute to the savings target. Many would consider this target to be a real challenge if achieved solely through the implementation of a single innovative initiative in such a short time.

Research literature (Wix, 1997, Venables et al, 2004, Blismas et al, 2005, Goodier and Gibb, 2007, Nadim and Goulding, 2010, Bew and Underwood, 2010, Larsson and Simonsson, 2012) and industry reports (National BIM Report, 2013, McGraw Hill Construction 2010 and 2011, Miles and Whitehouse, 2013) analyse barriers, drivers, implementation techniques and case studies for both BIM and Offsite. The civil engineering sector is moving towards multi-dimensional object-oriented design in a similar way to the building sector. Many believe that this will inherently encourage the production of ‘objects’ designed for manufacturing, especially if data can be sent directly to the fabricators. Construction is a ‘low information intensity’ industry compared with banking or finance (Hu and Quann, 2005). Nevertheless, civil structures are complex entities formed by various sub-systems and diverse components, many often of unique design. The continued reliance of the civil engineering industry on using paper-based drawings as a means of recording designs and fabrication data is inhibiting offsite innovation. Theoretically, with the ‘digitalisation’ of construction data it is expected that advanced automation in design, manufacturing and erection through BIM will increase offsite (Eastman and Sacks, 2008). BIM is the technology that allows construction data to be ‘machine readable’ and components to be manufactured without human intervention (Eastman and Sacks, 2008).
METHODOLOGY
Grounded theory was applied in this research to allow for insights into investigating the emerging industry processes, while avoiding the adjusting or steering of data towards previous theoretical frameworks and focused on a phenomenological approach and deductive derived theory (Glaser and Strauss, 1967). Unlike other qualitative approaches, grounded theory begins focusing on the conceptual scheme through a contextual way, avoiding any predetermined theory (Cassell and Symons, 2004). This investigation did not intend to focus on a distinct area, but rather to allow the research to unravel through a continuous comparative analysis of incoming data that enabled a conceptual development. The data collection period lasted six months and data was considered sufficient when ‘theoretical saturation’ occurred (Glaser and Strauss, 1967). The conceptual theory was initially established through a series of discussions with industry experts.

When the exact research question was identified, a thorough and focussed literature review was undertaken, including published research, industry reports and Government regulations. Twelve semi-structured interviews were conducted with BIM leaders and directors from leading UK construction contractors and consultants, software vendors, industry institutions and the UK Government. The interviews were thematically analysed in the six emergent areas: configuration management; construction management, scheduling and planning; interface management and information data flow; procurement and contract; object oriented design; and modelling.

FINDINGS
Many organisations, academic and industry experts have attempted to define BIM and offsite during the past decade. For this research, twelve experts first explained what each term meant to their organisation. BIM was seen by all as a platform for communication and collaboration. Also, although the focus is on data and information, attention is drawn to the way the design or modelling processes are managed and controlled (Figure 2). Recurring terms such as ‘correct’ or ‘improve’ show a positive attitude and enthusiasm towards this innovation. To summarise, in this paper, BIM is therefore an umbrella term for object-oriented modelling that relates to both vertical (i.e. buildings) and horizontal (i.e. railway, highways, etc) infrastructure, where the objects have extended attributes that can be leveraged to understand the content of a design and allow for a consistent platform of communication throughout the supply chain.

Figure 2 – Key words from research participants’ BIM definitions (Wordle, 2013)
Offsite definitions were more diverse and sometimes contradictory (Figure 3). Contractors saw offsite as a construction process, where components are fabricated in a factory or somewhere near-to-site and then transported to site for installation. For consultants, offsite is more of a means to achieve increased efficiency where products, either bespoke or from a catalogue, are manufactured in a controlled factory environment and assembled on-site. There was confusion between the terms standardisation, prefabrication and preassembly.

Previous Government Initiatives
While offsite has been promoted by the UK Government for generations, albeit using different terms such as prefabrication (Murray and Langford, 2008), the focus on high-powered information and communications technology has been somewhat more recent. In 2002, The Department for Trade and Industry (DTI) combined with the Engineering and Physical Sciences Research Council (EPSRC) to develop a programme of works, the Innovative Manufacturing Initiative (IMI). The IMI funded a theme called Meeting Clients Needs through Standardisation (MCNS), which orchestrated a group of focused calls for research programmes. The last two programmes funded predominately by the Department of Trade and Industry’s (DTI) Partners in Technology programme (currently known as Department for Business, Innovation and Skills or BIS) were Avanti and PrOSPa. Avanti’s core aim was to investigate and encourage collaboration through the use of Computer Aided Design (CAD) by arguing that managing information databases were more efficient than managing ‘drawings in a cabinet’ (Construction Project Information Committee, 2007) Avanti supported early access to information from all parties of the supply chain and work protocols, promoting improved communication and common information models, and was a stepping stone on the way to the current Government BIM initiative. PrOSPA aimed to encourage offsite solutions across the construction sector (Goodier and Gibb, 2007). PrOSPA was the predecessor to the industry-focused organisation BuildOffsite.

Both Avanti and PrOSPA programmes focused their work predominately on the building sector rather than civil engineering. Despite the downturn in the current financial situation in the UK, offsite is 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 civil engineering sector, but other applications have had little deployment (Gibb, 2001, Goodier and Pan, 2010) and this view was supported by the interviewees in this current survey. Some claimed that the civil engineering sector ‘thinks less
of their process and data possibly due to the size and duration of the projects’. Others debated the reasons for differences: in the building sector, learning from project comparison is less challenging as you can analyse, for example, the cost on a functional breakdown and compare the cost of a system from one project to another; in the civil engineering sector, because of the nature of the work, which is often broken down in different ways and assigned to different subcontractors on site, it is more difficult to compare on either a project-by-project or a contractor-by-contractor basis. Some consultants claimed that offsite was easier to develop for the building sector due to ‘object libraries’ and ‘catalogues of components’, reflecting the repetition in the construction.

Most participants agreed that the building sector is currently leading in implementation of BIM and offsite. The main reason was the software available is more focused on vertical construction. Software providers claimed ‘the building sector has instant gratification from BIM and it is less challenging compared to horizontal infrastructure where segmenting the model is a complex process’. Consultants argued that despite software for the building sector being ‘more mature’ the real challenges occur when large geographical areas demand the combined utilisation of Geographic Information Systems (GIS) and BIM. Government experts claim that less research on processes and data transfers is undertaken by the civil engineering sector which ‘lacks comprehensive data systems, such as Industry Foundation Classes (IFCs)’. Although most firms contributing to this research are involved in large-scale infrastructure projects, only one participant claimed that ‘some key civil projects (i.e. CrossRail) are using much more superior BIM techniques than any building project’ (Figure 4). To conclude, there was support for the building sector utilising BIM on a wider scale and being more aware of BIM processes (National BIM Report, 2013), but in civil engineering there were some best practice examples demonstrating the applicability of BIM within a complex infrastructure environment.

Figure 4. Bond street station complex BIM model (Vernikos, 2012)

All participants agreed that consultants used to lead the way in BIM technologies and methods, ‘starting from a position of strength’, predominately because of ‘their familiarity with the visual
aspect of the software and the rapid production of drawings’. During the last few years, contractors have been accelerating their BIM awareness, using it as an opportunity to achieve greater savings. In addition, UK Government is a main client of UK contractors and they are being ‘forced into rapid BIM implementation’ to maintain a competitive advantage. Nevertheless, consultants interviewed claim that contractors use BIM to focus more on the detailed design and the construction phases of the project and less on the operational and the maintenance phases. The UK Government representative interviewed highlighted the importance of BIM for the lifecycle of the project and claimed that the benefits of BIM in the design and construction phases are minimal in comparison.

ANALYSIS
Considering BIM’s effects on offsite, most participants thought that by the UK Government mandating BIM by 2016, the usage of offsite in the civil engineering sector will increase. Some were very enthusiastic, claiming that offsite is the missing link without which there are no easy mechanisms to ensure that design intent is translated into a fabrication intent that is manufactured effectively. In addition, it was claimed that only through BIM ‘one that designs precise digital objects can then fabricate them in factory conditions’. Others were more cautious, stating that there are many parameters that determine where and how to use offsite but ‘BIM helps designers take into account all these factors and make a more informed decision’. Notwithstanding, it was made clear that success depends on how organisations implement BIM and offsite in the model they operate. Despite the consistent opinion of most participants that BIM will positively affect offsite, one consultant claimed that BIM neither enables nor hinders offsite because BIM applies equally to on- and off-site work. The consultant believed that ‘offsite is on an upward curve and I don’t think that curve will become steeper since BIM was formally introduced to the industry’.

Configuration Management
As the industry is progressing through an increasingly digitised world, all participants agreed there will progressively be more automation, computerisation and manufacture in construction. The problem currently faced, predominately by contractors, is configuration management. When large numbers of offsite components are ordered, the contractors are challenged to locate and identify potentially faulty parts within multiple large and complex construction sites. With BIM, and the technology surrounding it, they claim to be able to track in real time ‘which bunch went to which site and from then how many were installed and where’. Therefore, embedding this information in the BIM design gives contractors greater control over offsite units, increasing their confidence by reducing risk and so resulting in more adoption of offsite. Similarly, consultants claimed that BIM can be used as a site management tool ‘that is linked to the actual design of a complex environment with prefabricated units’.

Construction Management, Scheduling and Planning
All contractors claimed that long ‘lead-in times’ are the greatest disadvantage of offsite and if not managed correctly, choosing offsite could add costs to the project and thereby increase risk. To prevent significant delays in the construction phase ‘information needs to be accurate, finalised and ready long in advance’. Lead-in times can be managed more effectively within a BIM environment. Contractors claim that BIM enables them to have a better programme that includes the manufacturing process, the delivery and installations linked with the design. Consultants also underline the importance of early scheduling and planning, especially when considering logistics in complex urban construction sites. All participants agreed that the supply chain benefits from timely decision-making through early contractor involvement that is
encouraged by BIM, independently of the contractual agreements. Opportunities for offsite can be identified and introduced as under a BIM working environment, due to this early decision-making process, ‘changes to the design can be made when they are less costly’, and ‘problems appear earlier’.

The software providers interviewed claimed that ‘BIM gives the opportunity for a continuum data sharing in a live design environment’ and see BIM as a trigger for leveraging the model throughout the process so that the design gets analysed, confirmed and used automatically by machinery to fabricate offsite components. Contractors and consultants partially agree that more reliable information would be provided to the offsite suppliers and fabricators and therefore less re-work would occur due to this ‘BIM-Offsite link’. Contractors argued that a high level of design is necessary for manufactured components, making it clear that they ‘need to be sure that the components they order or pre-fabricate will fit and will be assembled as the design indicates’. With BIM they claim to be able to assemble the structure virtually, observing the process before it commences onsite. Overall, the participants thought that:

- Firstly, through a better quality of information, their current offsite use will be improved and will consequently result in better quality offsite being produced.
- Secondly, better communications, triggered by BIM, will identify more opportunities for such solutions.

**Interface Management and Information Data Flow**

BIM was seen by most participants as ‘a good platform to engage different sectors and improve business-to-business relations in order to explore and benefit from opportunities’. All contractors perceived BIM to promote collaboration in the earlier life of the project, which is necessary for offsite implementation (Gibb, 2001). Contractors are adamant that BIM will help establish relationships and then those relationships will help identify potential for offsite. They predict ‘more and more organisations joining to design and construct together’, therefore creating more sophisticated solutions through these combined processes. Consultants also thought that BIM encourages coordination of different parties and departments to understand ‘who is doing what, when’. Examples were discussed where ‘during design meetings using BIM 3D models, the dynamics of the communication changed and less time was spent describing problems and more time was spent trying to solve them’. The participants believe that working under a BIM environment was a way to be ‘exposed’ to areas where offsite could be ‘a better option’.

All participants considered the way information is currently communicated in the construction industry to be a big issue. There are ‘very abrupt handovers of information, usually in document form’ which need continuous checking. Minor mistakes in design or misprints could lead to an increase in cost and construction time, especially when using offsite, as there is little or no flexibility when the components arrive on site. Some participants thought there is insufficient checking in civil engineering. This is because ‘the disruption to the team when someone is taken off the process to check the drawing and documents is huge’. Consultants believe that BIM affects the integration of the design team, so it is important to have good information flow throughout the supply chain. BIM with a shared working platform might provide a shared space where every change is tracked and is visible by colleagues and by other teams. BS1192 (BSI, 2007) makes a distinction between someone’s private work, the shared work in progress and the published work. Within that ‘shared’ environment, automatic checking and peer review is
viable, allowing issues to be identified in advance and discussed earlier in the process. This allows a continuous discussion and progression without abrupt information handovers and catastrophic ‘start-stop’ checking procedures. However, participants were unable to supply evidence of current projects working as described above. Some examples were discussed but little substantiation was provided.

**Procurement and Contract**

Contractual agreements and procurement under a BIM environment is at the forefront of the Government’s agenda. Many participants believed that ‘BIM should be a catalyst for changing the way the industry procures’. All participants thought that the current procurement methods hinder the development of offsite through BIM. Contractors thought that procurement mechanics can really affect the development of offsite and highlighted that ‘design and build contracts enable BIM driven offsite’. Consultants agree that early contractor involvement ‘can help to identify when offsite can be of value’ therefore appropriate contractual agreements will enable ‘earlier’ decisions, which is ‘the key’ to successful implementation. Consultants also believe there is a problem when models, drawings and other data are produced but circulated as ‘only for information, do not use’. All parties agree that producing data through BIM comes with a great responsibility, as mistakes are easily identified and traced. Consequently contracts need to include the required quality of information and state every party’s responsibility, accountability and liability facilitating more clarity; this would result in an increase in confidence that would encourage or ‘invite’ innovative offsite solutions. Reviewing the principles and assumptions of BIM (BuildingSmart, 2011), it only seems to work when fully within a collaborative contractual environment. Failure to acknowledge this limitation may adversely affect the successful implementation of BIM across the industry.

**Object Oriented Design - Virtual Objects, Virtual libraries and Assemblies**

The software experts claimed that current BIM software is ‘not that great for assemblies’. Currently, existing software does not allow, practically and in any automated form, identification of opportunities for offsite more than ‘in the old document and drawing based design’ and construction process. However, BIM has the potential to promote offsite by identifying repetition, which will enable greater cost-saving through mass customisation. BIM should ‘be more about information, productivity, re-usability and one input - many outputs but there should be more automation within the model to identify and promote areas for further cost reduction from economies to scale through offsite’. Examples were discussed from abroad (Singapore) where a decade ago system was introduced in which a BIM model could be checked against Building Regulations and planning permission automatically online. According to the UK Government participant, the ‘Technology Alliance Group’ is currently tasked by UK Government to challenge the way software vendors allow ‘BIM libraries’ to be created or other ways of grouping components or systems. ‘The real challenge is on the way the software will manage assemblies, what kind of assemblies may occur, what kind of components may contain and how can they be shared’.

All ‘BIM authoring tools’ and ‘information transfer protocols’, such as Construction Operations Building Information Exchange (COBie) and IFC can be used to share assemblies, even though a series of problems occur that software developers and UK Government task groups are trying to address. The UK Government appreciates the potential for offsite and they are aware of its documented advantages, but they are not willing to ‘regulate or demand’ a specific software or technology to promote it, saying ‘The UK Government, as a client, gave COBie to the supply chain and it is up to them to respond accordingly’.
The challenges include:

- Firstly, the type of functions or technology that will be used by the application to create and save offsite components as a library resource.
- Secondly, ‘once one has created these assemblies, how would the attributes and classifications work?’ The key issue is whether the assembly will override the content or vice versa: for example, does an assembly get scheduled but the content does not, or does the content gets scheduled but not the assembly?
- Thirdly, exporting and sharing assembly data in a BIM environment is considered by respondents to be an issue despite COBie’s and IFC’s implementation. BS8541 (BSI, 2012) was created to assist in this ‘computerised data exchanging environment’ aiming to encourage manufacturers of offsite components to recommend designs, fix costs and demonstrate the quality of their products through a ‘template’. Nevertheless, ‘manufacturers are wary of this process as the information required from them is not clear and intellectual property (IP) issues arise’. The ‘templates’ mentioned by BS8541 (BSI, 2012) were criticised as having ‘a lot of attributes but no values’.

Civil engineering contractors criticise the existing practices, claiming that most of the software and the processes accompanying them are mainly relevant for the building sector. They have experience of software that allows ‘partial grouping’ for the creation of assemblies of components. Some contractors are investigating the potential for BIM and offsite, aiming to create an internal 4D installation manual. This ‘catalogue’ will contain lists of components including detailed costing, installation and material properties. The design staff will then be able to choose and order a component for manufacture. The tool will have the capability to ‘show how the structure will come together’. The contractor developing this ‘virtual design catalogues’ admits that very little is directed towards the civil engineering sector.

Consultants also agree that the ‘software right now focus primarily on onsite building work rather than offsite’. They claim that software is not appropriate for creating different prefabricated objects or elements with different materials and layers. When there is a need to create such objects they will use software and ‘export the models to the software used by the BIM platform’. Other consultants discussed additional issues with object libraries. If assemblies are used, on a project-to-project level, the definitions and the shared libraries have to be identified otherwise there are problems with definitions of elements and identifying quantities of elements or components.

Software providers admit that ‘the software is in a maturing stage’, but they claim to be working hard on preparing standards and facilities for custom component preparation to facilitate assemblies, parametric objects that represent building components. They understand that it is ‘an area that is evolving’ and they are finding it very difficult to standardise civil engineering components to segregate or subdivide the linear horizontal assets. Examples were discussed focusing on mature assembly systems (i.e. drainage) that have already been standardised and software providers claim the modelling of such offsite systems can be much more efficient through any BIM technology.

Modelling – Modelling Capabilities, Model Quality and Data richness
All participants claimed that BIM enables offsite because of the 3D elements that allow greater visualisations. Nevertheless, increasingly, some contractors find that when models are received after the tender, the actual ‘BIM model’ has very little value in it. So ‘at times we have to re-model because the designer models in a way that does not reflect the way that the project will
be built’. The model is vital for construction programming and therefore the designer has influence in that process and is the key for lead-in times when considering offsite construction. Once again contractors claim the problem lies with the procurement process and the contractual agreement. Contractors admit that ‘the contractor fraternity is still asking for 2D drawings’ and examples were discussed where consultants designed in 3D and where asked to ‘cut the drawing in 2D for the constructor to understand it’, which was deemed ‘counterproductive by both parties. Consultants argue that ‘the 2D mentality from the constructors’ side has to change’ and the contractors interviewed agreed with this statement.

An area of great debate is the way modelling or designing skills affect the identification of offsite in a BIM environment. Some contractors claim that there are examples of some designers who struggle ‘with the technology and at that point BIM becomes a hindrance not just to offsite but for the construction process itself’. Meanwhile, other contractors admit that the ‘tools’ have great capabilities and ‘are far beyond their current abilities to use them to their full potential’, indicating a training skills gap. Most contractors’ felt the ability of the ‘software operator’ to identify opportunities for offsite is crucial and therefore ‘software operators’ in a BIM environment ‘have to be engineers rather than technicians’. The contractors were insistent that as the ‘designer plays a vital part in the construction process as they construct the project virtually - therefore it is an engineer’s job’.

In contrast, consultants claim that there is no need for complex training in order to operate the BIM software correctly. They believe ‘inter-tier communications’ are crucial to ensure that skilled technicians are using the correct information, library or layer. Responding to the contractors’ view about designer BIM capabilities, consultants believed engineers need only be aware of the software’s capabilities and ‘operate it for everyday tasks’, but nevertheless a ‘modelling champion’ that specializes in the software will always be required to do complex aspects of projects.

The software providers believe that the operator is responsible for using the software correctly in order to be able to ‘identify quantifications for offsite’. Some examples discussed included the use of BIM to sub-divide a design into components that will significantly reduce logistic and installation problems due to size or height of the component.

**CONCLUSION**

Both BIM and offsite as concepts are not fundamentally new, but terms referring to the ideas have changed over the decades to reflect industry trends. During the past few years a number of successful case studies on the use of offsite within a BIM environment have been published (Eastman et al, 2011). The majority of these are focused on the building sector, with the United States leading BIM implementation. Within the UK, early adopters such as the Ministry of Justice are using BIM with offsite for prison blocks and some ‘best practice’ examples are producing promising results (MoJ, 2013).

Despite high expectations from the literature and some practical success in the building sector, very limited application of offsite through BIM is witnessed in civil engineering. The participants in this research attempted to identify evidentiary examples to prove that BIM enables, promotes, increases or improves offsite, but apart from some aspects of ‘key infrastructure projects’, no evidence could be provided. The UK Government provided examples where ‘projects started using BIM from the RIBA-Stage C phase and this was deemed fundamentally flawed’. Therefore, based on this principle; some participants’ examples were
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disregarded as their ‘BIM’ elements were merely 3D visuals or the BIM implementation was encouraged not for its efficiencies but for commercial reasons. When participants were not able to provide evidence, they claimed that the statements were going to materialise during BIM level 3. Nevertheless, as the UK Government confirmed during the interview, currently BIM level 3 is yet to be clearly defined.

Offsite is a more ‘familiar’ concept to the civil engineering sector than BIM, with precast concrete elements and bridge construction or tunnelling often employing offsite (Vernikos et al, 2012). However, throughout the data collection process of the research summarised in this paper many participants confused the terms ‘standardisation’ with ‘prefabrication’ and the term ‘offsite’ was not clearly understood. Economies of scale are achievable through standardising offsite elements and BIM may influence the process drastically, yet the one does not automatically lead to the other. One contractor underlined the distinction, claiming that ‘standardisation is an aspect of BIM, but a minor percentage of civil engineering works is standardised’ as parametric and logistical flexibility is needed. With consultants saying that ‘contractors don’t know what they want’ and contractors claiming that consultants give them ‘empty models’ the confusion is not limited to offsite terminology but also to BIM implementation.

After analysing the responses of twelve of the BIM and innovation directors representing leading UK consultants, contractors, software vendors and construction industry institutions, it is evident that there is a clear belief that BIM will improve and increase offsite construction in civil engineering. Nevertheless, there is still very little proof that this is currently the case. It appears from the findings presented here that BIM does have the potential to improve the quality of existing offsite methods and solutions, although investment will be needed in training to get the best out of the complex software. Once this is in place, it may raise industry confidence and therefore it could indirectly increase the offsite usage overall.

REFERENCES


APPENDIX F  OFFSITE IN INFRASTRUCTURE - WORKSHOP REPORT 1

Offsite Construction in Infrastructure: Workshop report

Contents

Abstract

A series of initiatives are currently taking place in order to modernise the UK construction industry, with a governing aim to reduce project costs through improved resource and data management. The use of offsite construction methods and standardisation have been deemed appropriate approaches for reducing costs and construction time, while increasing construction quality. Changes in information technology, such as Building Information Modelling (BIM), coupled with supplier investment in new production processes are driving new thinking in offsite construction. This enables clients, consultants and contractors to rethink the ways in which traditional flows of information and products form to create new infrastructure. Thinking is driven in part by adoption of best practice from allied manufacturing industries. This report explores the benefits gained through adoption of new techniques, as well as the risks and barriers that might slow or prevent adoption of these new techniques during the next decade. The report concludes with a summary of strategies for clients and the supply chain.

1. Introduction

CH2M HILL and Loughborough University have been involved in a collaborative research programme focusing on offsite construction for the past four years. In December 2013, a workshop took place to examine aspects that may drive or hinder the development of offsite throughout infrastructure and identify strategies to overcome them. The purpose of this workshop was to capture the views of different parties across the infrastructure supply chain on benefits, risks and strategies of offsite and compare them with existing findings from academia. A total of 11 senior managers (i.e. director level) from major UK clients, contractors and consultants were invited, with roles focusing on the rail sector. The workshop was divided into the following four distinct stages:

a. Participants were asked to identify key benefits of offsite they were aware of, write them on notes and affix them to a large board. The notes were grouped according to their nature (e.g. health and safety, cost, etc.) and then participants were presented with the benefits as identified by academia. The group was encouraged to compare and debate on the findings. At every stage, they were asked to rank the identified benefits using a separate sticker.
b. Following the same process, participants were asked to identify key risks of offsite they were aware of, write them on notes, affix them to the board and debate the points.

c. Similarly to the previous stages, participants were asked to identify strategies for implementing offsite that they would expect client organisations or the supply chain to undertake. Once again, the participants wrote them on notes, affixed them to the board and debated the topic (Figure 1).

d. Finally, participants were asked to use stickers to rank the future uptake of offsite in the near and mid-distant future in particular sectors (Figure 2).

2. Benefits

The most important benefit of offsite construction identified for the infrastructure sector was quality. The majority of participants claimed that by using offsite there was not only greater consistency ‘by minimising variability of specifications and the overall build form’, but also improved quality on the whole by ‘getting it right the first time’. Quality was one of the most recognised benefits and equally was deemed as the most important by all participants. Safety was also one of the most acknowledged benefits, amongst contractors and clients in particular. Participants emphasised that by having less staff onsite, there is less potential for accidents.

The assembly process was discussed and activities, such as ‘controlled lift’, were seen as safer since ‘most construction activities take place in a safer environment away from the construction site’. Nonetheless, recent data from the Health and Safety Executive (HSE) discussed by Buildoffsite (Krug and Miles, 2013) shows that the injury rates for general manufacturing and construction sectors have converged in recent years, with a slight divergence only in fatal injuries (Figures 1 and 2). The reasons for the discrepancy in industry’s perception against statistical data required further research which will be discussed in an upcoming journal publication.
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The most debated benefits were associated with the programme and how offsite affects it, despite it being deemed less important than quality and safety. Participants discussed how the programme is improved by faster construction or erection time, with one claiming that ‘through offsite construction we can achieve 30% improvements on the programme’. The group also agreed that offsite provides greater predictability of schedule and ‘despite longer planning time there is faster on-site delivery’. An additional point linked to the programme was the reduction of disruption on site due to better management of vehicle movements and site-space requirements. Nevertheless, ‘offsite should be considered early for this benefit to materialise’. Furthermore, cost-related benefits were of equal importance to the programme. The higher cost certainty and cost effectiveness through standardisation of offsite solutions were closely linked to the ‘increase of value’ of a project. Offsite systems were seen as more efficient in reducing overall costs, although it was argued that these reductions often appear to be offset by increased transportation costs.

With regards to significant, addressing skills shortage through offsite construction was ranked amongst the most important, but it was not mentioned by the participants. This benefit emerged when the group reviewed benefits identified by the literature. Sustainability was also discussed but not seen as a benefit of critical importance. Participants believed that offsite construction provides reductions in energy consumption, waste and noise. Some participants from contracting organisations claimed that they use precise metrics to measure sustainability benefits in the building sector (e.g. schools) and due to the similarity of the projects re-occurring, they are experienced enough to be confident in the accuracy of their metrics.

3. Risks

Participants discussed current offsite risks and procurement was identified as the most important risk by all parties. The splitting up (sometimes excessively) of contracts coupled with over-controlled procurements often makes offsite a ‘non-viable business case’. Certainty of project pipeline to generate IRR (Internal Rate of Return) on facilities was seen as critical. It was underlined that there is a need for large scale programmes, such as CrossRail and High Speed 2 to ensure that ‘offsite suppliers do not go bust’. Nevertheless, examples were discussed where large clients’ procurement intent and ‘their control of financial exposure to single Tier 2 suppliers have been seen to act as a barrier to implementing specific offsite solutions as it is seen to reduce competitiveness’. Procurement is the main limitation to achieving economies of scale with offsite solutions; consequently, offsite usually appears to be more expensive. Nevertheless,
Second in importance but certainly the most discussed risk to offsite was thought to be the process. Participants acknowledged that offsite is not always considered at the early stages of a project. Therefore, poor process and insufficient understanding of the importance of the process hinders its adoption. Retrospective application of such solutions is often sub-optimal. Participants closely linked the process risk with the design risk. It was echoed by all that ‘design has to be well developed and locked at an early stage’. Some participants argued that standardised designs should be used more at the early stages but others thought that there are ‘insufficient design developments’ (e.g. limited offsite design options) which result in the ‘over prescription of solutions’. When offsite solutions are perceived as high risk, issues of liability (or transfer of liability) of design occur. As a result, when offsite options are employed, the design costs can often be higher.

In addition, some argued that the benefits of BIM are not being used and may increase design risks as ‘BIM type models are essential for offsite’. Examples were discussed where BIM models were ‘empty’ (i.e. lacking key data) so BIM at times is seen as a design risk, although it was underlined that if BIM is used properly it is essential for the uptake of offsite.

Lack of investment and initial costs were recurring topics throughout the discussion on risks. Lack of initial investment and overall initial capital cost was seen as a significant blocker to offsite, especially from client organisations as ‘the CAPEX risk was perceived too great’. Equally as important to the lack of investment was the perceived inflexibility of the design. Offsite was seen as being rigid and inflexible in relation to late changes, ‘late changes are often due to failures within the project processes’ which increases risks. At that point some participants argued that ‘infrastructure is a prototype industry but it should not remain that way’.

The overall perception of offsite through the wider construction industry was heavily debated; the discussion expanded and covered topics such as investment on research and the general adoption of innovation. Participants agreed that, due to a legacy of poor results and with offsite seen as ‘hit and run’, the construction industry is reluctant to adopt it. This negative perception was seen by the group as an overall lack of awareness. More specifically, some thought that clients were unaware or misinformed of the potential of offsite. In general, the industry is change-averse and the fact that ‘the lack of familiarity with offsite puts project managers out of their comfort zone’ makes them very hesitant. Moreover, existing technical standards were also seen to be a blocker to offsite. The participants believed that they are inflexible and out-dated, ‘as
4. Clients' Strategies

The leading strategy recommended to clients was early supply chain engagement. ‘Early engagement with the whole team will demonstrate leadership, belief and commitment to offsite’. The client should engage with the design team at the concept stage, to develop an offsite strategy, and include the contractor to contribute to the design requirements. Subsequently, the client should be clear with regards to time and cost targets. This will ensure that the programme includes these goals and the team has a clear understanding of their ‘goals’. Finally, ‘the clients should engage early with the design teams to review standards and specifications’.

The second most important strategy recommended focused on programme integration. The participants believed that ‘lager procurement packages with greater volume of works’ would increase the uptake of offsite. This will be encouraged by ‘economies of scale through potential programme integration’. The ‘consistency in approach by clients and their support towards a long term investment will raise the industry’s confidence in offsite’. All participating clients agreed that this would enable more offsite. Equally important were deemed the recommendations on procurement strategies. The supply chain claimed that ‘incentivising value criteria in ITT (Invitation to Tender) will promote offsite construction’. ‘The link between business benefits and performance specifications has to be established during the procurement stage, therefore there is a need to align procurement and contract models with the processes. ‘Current contracts stifle offsite rather than empowering such solutions’, a recommendation predominantly supported by consultants.

The third most important recommendation focused on the overall strategic thinking of client organisations. The supply chain, led mainly by contractors, expects clients to ‘be forward thinking’, ‘promote best practice’ and ‘provide thought leadership that encourages standardisation’. The clients should be ‘more transparent with the supply chain and communicate the strategic intent’ (i.e. costs, investment intent) which will ‘encourage synergy opportunities for the supply chain’. This ‘partnering will share CAP-EX exposure and encourage the adoption of offsite’. Nevertheless, for all the above to be achieved the client ‘should specify clearly at high level the outcomes expected’ and ‘collaborate with the supply chain in the evaluation of requirements’.

From the strategies discussed, 3D design and BIM played a key part. Participants thought that client organisations should make ‘BIM-type technologies mandatory’, thus ensuring ‘good quality data from start to finish’. This will firstly encourage ‘the development of standardised designs’ and secondly ‘identify opportunities for temporary offsite capabilities (i.e. aid access, logistics)’.

Finally, industry standards and specifications were debated. The supply chain thought that client organisations were ‘too rigid’ and ‘inflexible’, which ‘made it difficult to approve offsite solutions or products’. Clients thought that specifications should be more ‘performance-orientated’. All participants agreed that there is a need for more documentation (i.e. guides, standards or specifications) on offsite that would challenge the design teams in all firms to
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5. Supply Chain Strategies

First, the dominant strategy recommended by the supply chain participants focused on design issues. The recommendations focus on the quality of data communicated through the lifecycle of the project, which had been affecting the quality of offsite products. This can be achieved by 'embracing BIM from the beginning to the end of a project'. In order to improve the design process, it is critical to first increase investment in people and technology solutions, aiming at a higher output. This will accelerate the adoption of existing software utilisation and support the offsite implementation processes.

Second, an overarching need identified was the increase in integration throughout the infrastructure sector. One of the key elements acknowledged was an early engagement with the supply chain, especially for Tier 2 contractors. This could be supported by supply chain strategic long-term partnerships in order to address client needs, fund product development and promote innovation. These partnerships should aim to promote the development of solutions that require buy-in from multiple Tier 2 and 3 suppliers. It is essential though that 'suppliers with the right skills are identified'.

Raising awareness and understanding was recognised as the third most important strategy. It was made clear that both the supply chain and the client organisation 'have to understand what drives offsite implementation on each side and also understand the outputs required so they can collaborate to engineer relevant inputs'. Protocols were also discussed, but only client organisations ranked them as important, believing that the promotion and implementation of cross-industry protocols and accreditation platforms would boost market confidence.

Finally, cost reduction strategies were discussed, but they were not deemed imperative. Participants recommended a more transparent approach to the benefits achieved by offsite construction in past projects. This 'transparency will create a more credible business case and increase investment'. In addition, further 'transparency will demonstrate a maturity of process which would drive cost reduction and overall product efficiency.'
6. Analysis

In comparison to previous offsite industry reports, predominantly focusing on the building industry there have been significant developments (Goodier and Gibb, 2007, Miles and Whitehouse, 2013). In the past, almost half of the strategies adopted by firms aiming to increase their uptake of offsite revolved around ‘learning and training’. The participants believed that the industry has the technological capabilities and the know-how to increase the adoption of offsite as well as a good understanding of its benefits (Figure 5). It was made clear that offsite development is hindered predominantly by ‘procurement’ and ‘process’ (Figure 6).

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<td>5 Overall perception</td>
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<td>6 Technical Standards</td>
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Figure 5. Top benefits of offsite in Infrastructure and Building Sector

The term ‘offsite’ was seen by some as ‘the manufacturing side’ and they argued that ‘the final deliverable should also be about design for modularisation, design for standardisation, and reconfigurable designs’. The various sector groups also discussed the difference between offsite components being produced in a factory and the ones fabricated at near-site factories due to logistical benefits. These ‘flying factories’ are currently ‘used in school building projects, nevertheless this process can be used in infrastructure and deliver great benefits’.

Findings from the workshop suggest that clients should take a more proactive role in offsite adoption. Clients’ responsibility in driving innovation and efficiency has been on the construction agenda for decades (Constructing Excellence, 2009) and has been discussed in several industry reports (Figure 7).
The strategies recommended by workshop participants for the client organisations to consider were significantly more in number than those for the supply chain. In total, the key recommendation included:

a) Client organisations should engage with each other and discuss how to increase offsite best practice. Following this, they need to provide 'thought-leadership' to their supply chain by communicating their goals and aspirations in a transparent way. The client organisation should lead in producing a document discussing how to implement offsite ‘from the very beginning’. That document should not only recognise the driving behaviours, but also identify specific tasks and benchmarks.

b) All participants agreed that the industry needs more guidance focusing on commercial processes. These guides should be in collaboration with organisations that promote technical and commercial knowledge, such as CIRIA, ICE, RICS, etc.

c) A piece of work that would significantly help realise offsite would be to characterise all the investment programmes in specific sectors (e.g., in rail and underground) and ask clients and the supply chain ‘where does everyone need to be?’, ‘how do we best manage risk?’, and ‘how do we ensure that everyone comes out with a profit?’.

d) The supply chain should also draft a document for clients with advice on what should be considered and discussed.

The participants felt that ‘the industry should act now’ and capitalise on all the benefits that offsite offers. Currently there are reviews being undertaken in major projects in order to implement more offsite (such as CrossRail), but at this stage it may be too late for offsite to be considered. ‘There are a lot of ongoing discussions but there is an urgent need to put the theory into action’. For infrastructure, we are coming to an offsite ‘renaissance’ and there are great opportunities for offsite due to the current investment programmes, proven benefits from the building industry and recent technological developments.
7. Conclusions

This workshop provided a good platform for clients and the supply chain to engage and discuss current perceptions of offsite in infrastructure. The next workshop will focus on creating an offsite implementation plan for infrastructure, taking into consideration the benefits and risks discussed and building up the already identified strategies.

References


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APPENDIX G  OFFSITE IN INFRASTRUCTURE - WORKSHOP REPORT 2

Offsite Construction in Infrastructure: 2nd Workshop report

CH2M HILL and Loughborough University
Vasileios Vernikos
Offsite Construction in Infrastructure: 2nd Workshop report

CH2M HILL and Loughborough University

Abstract

The use of offsite construction methods and standardisation have been deemed appropriate approaches for reducing costs and construction time, while increasing construction quality. Changes in information technology, such as BIM, coupled with supplier investment in new production processes are driving new thinking in offsite construction. This enables Clients, Consultants and Contractors to rethink the ways in which traditional flows of information and products form to create new infrastructure. This workshop is the second in a series of workshops investigating different strategic actions with organisational, industry support organisation and government focus to deliver the ‘ideal offsite project’. A key recommendation from the workshop was the development of a series of offsite hubs on specific industry sectors.

1. Introduction

CH2M HILL and Loughborough University have been involved in a collaborative research programme focusing on Offsite Construction for the past 4 years. At the end of 2013 our Offsite Construction workshop series was launched with the aim of increasing collaboration and encouraging the implementation of Offsite solutions and processes. Following on from the success of the 1st workshop on ‘Offsite in Infrastructure’ in December 2013 a follow-up workshop was held on 23rd May 2014. This 2nd workshop took into consideration the benefits and risks discussed during the 1st workshop and investigated how to develop specific strategies in more detail. The purpose was to distil the findings of the previous workshop and create a specific plan of action for Offsite uptake in the industry as a whole. 20 participants were involved from senior management i.e. director level, representing major UK contractors, consultants, clients, academic and industry institutions.

The workshop was divided into the following distinct stages:

a. In the beginning the participants were reminded of the findings from the 1st workshop. The conclusions were presented to them and they were given a detailed report outlining both the process followed and the outcomes.
Offsite Construction in Infrastructure: 2nd Workshop report

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b. Participants were divided into 3 groups (blue, the red and the green) containing a variety of participants: clients, contractors, consultants and institutions’ representatives. Each group was asked to map a list of actions that should be undertaken during the lifecycle of a project so to enable the application of Offsite. Each group was provided with a poster and several books of post-it notes in order to map the development of offsite over 5 project stages - Feasibility, Optioneering, Design, Delivery and Handover. Following this, each group presented their poster and findings to the other groups (Figure 1). All posters were discussed and a summary was drawn.

c. Following the same process, the 3 groups then produced a list of actions that should be undertaken by the supply chain in order to enable the use of Offsite (Figure 2). Each poster was divided into Year 1, Year 2 and Year 3. Following this, each group presented their poster and findings to the group. All posters were discussed and a summary was drawn.

d. Finally, the 3 groups were encouraged to produce a list of actions that should be undertaken by industry support organisations that would support the industry in employing Offsite. Each poster was again divided into Year 1, Year 2 and Year 3, with each group presenting their poster and findings to the group (Figure 3). All posters were discussed and a summary was drawn.

Figure 1. One of the 3 groups presenting their work

Figure 2. The three groups developing their offsite strategies
2. The ideal Offsite project

Feasibility Stage
During the early stages of a project, having an informed client is key. The project team should engage with contractors and clients in early communication with the aim to help the clients develop precise specifications that will enable offsite. The project specifications should include performance specifications with a project team target. The client specifications and overall approach should be output and outcome focused. Moreover, both BIM and Offsite construction should be included in the I.T.T stage as a standard. An offsite informed brief was also deemed critical. Nevertheless, the aim is to have the minimum brief, therefore keeping the options open. The brief needs to be outcome focused. Overall collaboration - and more specifically partnering - is essential. Integrated project insurance could eliminate many current barriers to Offsite adaptation. Project ‘value based procurement’ and a ‘procurement process weighted in favour of Offsite solution’ would further encourage the project team to prioritise accordingly.

Optioneering
When assessing different options the project team should ‘challenge existing approaches against new practices and compare their benefits’. It is important to encourage ‘true optioneering’ and attempt to understand enablers and drivers of different options (e.g. cost, sustainability, etc.). ‘The aim should be to achieve a balance between cost and advantage’ and ‘not just the cheapest option’. ‘The solutions chosen for one project may have large financial savings when applied to future projects’. The team should focus on ‘exploiting existing modular design options as there are several currently available for all types of projects’. If this is not sufficient, then considering new technologies and ‘engaging with suppliers and tier 3 contractors will add to the list of options available’. This process will also allow the project team to understand the supply chain’s capacity and capabilities. Other considerations for the project team are an ‘onsite industrial construction’ approach – ‘There is no need to fabricate components in factories far away if it makes financial and practical sense to fabricate them onsite’. Current developments in the adaptation of BIM will enable a parametric object-oriented design where there will be a public offsite repository (See Section 5).

Design
The use of BIM should be the principal approach at this stage. BIM should be used to author models for design, constructability and sequencing. The use of standard specifications and standard products (from product libraries) should help illuminate ‘issues’ in detailed design. It is important also ‘to complete 90% of design before delivery starts’. ‘Projects reach a point beyond which offsite cannot be or should not be accommodated, that is at preconstruction’. From this stage onwards it is too late to influence the use of offsite but rather to ensure that the offsite solutions and processes employed are implemented successfully.
3. Organisational Strategies

The first action an organisation should undertake, irrespective if it is a client, consulting or contracting organisation, is to create an Offsite strategy. Different organisations have different targets and structures therefore ‘focus groups’ should concentrate on discussing organisational processes and aim to ‘craft the offsite strategy’. It is critical for the strategy to have ‘high level buy-in’ and a ‘clearly defined business vision led from the top’. ‘The Offsite strategy should state the reasons and the needs for change’. One of the aims of the focus groups would be to help standardise the offsite processes. It is important not just to focus on the standardisation of components, but the processes also. In particular for infrastructure, the focus groups should ‘think of repeatable processes rather than products themselves – processes that may potentially encourage the installation of different products in the same way’.

The Offsite strategy should include a research and development (R&D) fund which will have the capacity to ‘unlock idea generation and enable new offsite techniques’. The R&D fund should be assessed annually and amended accordingly after reviewing the KPIs, needs and the previous year’s overall performance. Part of the strategy should also be a recruitment plan, focusing on hiring staff that have offsite capabilities. Firms with effective offsite capabilities should ‘recruit staff with domain knowledge’.

In addition, a key section of the Offsite strategy should be a ‘training and education plan’. This will look into growing ‘organic capabilities’. As the Offsite strategy is implemented new roles will be created with new responsibilities. When these have been identified, a ‘training scheme should be worked out’. The education plan should not
focus just on ‘technical staff, but also for senior management, to ensure an ongoing offsite culture and ethos. The training plan should have a culture focus and ‘a general goal to raise awareness about Offsite throughout the firm’. Implementing an ‘offsite culture’ throughout an organisation is about ‘the right people and the right approach’. This includes appropriate training, expertise and experience but also clients should define ‘offsite appropriate’ procurement policies. It is important to be clear to all staff that the offsite strategy is ‘not mandating offsite’, but encouraging offsite. Through continuously informing and educating staff of options available and their benefits, Offsite should be considered, and deployed where it adds value. The strategy should look at how to ‘create multi-functional high performance teams’.

It is important for the strategy to include and apply metrics on the Offsite initiative within an organisation and measure success. KPIs should be applied annually and ‘they should drive behaviours’. Results should be articulated and published. ‘Measuring and demonstrating continuous improvement’ will reinforce the confidence of senior staff resulting in increased commitment to the initiative. ‘By identifying good ideas, celebrating and recycling, a firm can gain better results and continuous improvement’. Firms should embed within their Offsite strategy a ‘co-operative approach rather than a competitive one’.

To maintain momentum and implement the strategy properly a series of market/sector groups should be created. These ‘offsite-focused Implementation groups will be dedicated to deliver the actions of the strategy’. Those groups (or hubs) would include a variety of senior staff and team leaders not focused solely on technical expertise. The groups should consider defining roles for Offsite responsibilities and the creation of collaborations with tier 2 and 3 contractors (suppliers) and analyse the supply chain development process in their market/sector. The suppliers need 3 key things – clear communication, visibility of demand and early involvement. Suppliers are worried that they would give their ideas to the clients and the client then would go and procure them at the cheapest possible price, therefore, informed clients are important, clients that understand and support the process. In addition, tier 2 and 3 contractors ‘need to understand the direction of travel of clients in order to come up with the solutions that they can provide’.

When this has been discussed and embedded in the organisation’s offsite strategy, the next step would be to create an ongoing ‘Offsite excellence group’. This group would have the expertise and responsibility to advise the business ‘on how to deploy offsite’. This ‘team would be the technical experts’. This group should ‘continue to engage with contractors and specialist suppliers, ensuring they are aware of new innovative solutions’. Engaging and collaborating with the industry should include tier 3 contractors as they will be delivering a significant part of the offsite solutions'.

Figure 4. Organisational strategy from one of the three groups
The aforementioned Offsite strategy considerations apply equally to client organisations. Clients have ‘the opportunity to influence decisions and therefore carry greater responsibility’. Firstly, it is imperative that they \textit{inform the industry of their workforce and pipeline}. This will increase the confidence of the supplier to invest, as the longevity of the pipeline will help ensure security. Therefore, ‘large programmes and return clients’ have the potential to see greater benefits from Offsite. The client organisations should also ‘clearly articulate and estimate the expected benefit from the deployment of Offsite’. This could be cost, quality or time focused. The clients, through this process, should \textit{hold the supply chain accountable} for achieving their targets through Offsite solutions and process.

Summarising the organisational strategy section of the workshop, key actions would be to define the vision and create the Offsite strategy, then define the roles and the people who will promote Offsite. Identify dedicated groups that will drive Offsite within the organisation, run the strategy and promote that vision. It is important that senior management allocate funding for this initiative, including for research and development. ‘It is all about people and behaviour’, ‘embrace the offsite mentality’ and have multi-skilled people to take hold of that responsibility, to run with it and implement it.

\section*{4. Industry Support Organisations Strategies}

Industry support organisations ‘have great responsibility’ and can make a significant difference in materialising Offsite in infrastructure. Such organisations include institutions (i.e. the ICE, IStructE, IMechE, CIOB and RICS), trade organisations (i.e. BSRIA, TRADA, SCI, British Precast), industry research organisations (i.e. AITE, CIRIA, Constructing Excellence), lobby groups (e.g. BuildOffsite, etc.) and Universities (e.g. Loughborough University). Support organisations in collaboration with the Government ‘have the ability to develop industry wide guidelines similar to the BIM initiative’. The uptake of BIM has been ‘extremely rapid’ over the past few years and a similar approach could be adapted for Offsite. One of the suggestions was for overarching organisations to support the creation of \textit{sector hubs} and cascade the outcomes and actions to regional or \textit{local action hubs}. This was thought to eventually develop an ‘offsite sector’ on its own.

An \textit{education plan} was discussed with academia at the heart of it. Some participants thought that universities have to change and that they are ‘a bit set in their ways’. Universities should focus on developing multi-functional multi-disciplinary degrees and civil engineering courses should include topics such as Offsite construction and manufacturing. Other suggestions included ‘mandatory Offsite courses’ in civil engineering degrees and the development of an MSc in Offsite construction. In addition to universities, education in schools was discussed, including initiatives such as from Lego to Google’s Sketch-Up. Schools should visit more Offsite manufacturing plants, etc.
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As a whole, industry support organisations should 'focus on public engagement'. A 'Big focus is needed' in changing the image of construction in order to attract higher calibre multi-skilled individuals. It is important to 'consider diversity and inclusion' in the agenda. The public engagement plan should include social media and general media, not just construction focused magazines, etc. Media productions such as TVS Grand Designs help change the image of construction with a building focus, but 'infrastructure still has a long way to go'. There are significant differentiators for offsite construction in infrastructure that make it even more viable for infrastructure, and they have not yet been communicated properly. 'Construction needs a strong communicator and advocate who appeals to broader public opinion. "We need the Professor Brian Cox of infrastructure" to communicate that construction is "cool". The public engagement plan coupled with the education plan should result in 'inspiring young people' to join the construction industry. These 'bright young minds' should not just be civil or structural engineers, but also software analysts, mechanical and electrical engineers, etc. Within the discussion about public engagement and the image of construction, the terms used to describe 'Offsite construction' were also briefly debated. Other terms used for the same process include 'factory thinking', 'industrialised construction', 'design for manufacturing and assembly (DFMA)', and 'flying factories'. Participants agreed that terms such as 'standardised' or 'preassembled' send the wrong message and 'better terms should be used with smart construction' being one of them.

5. The Government

Throughout the industry, BIM is seen to enable the use of Offsite (Vernikos et al. 2014). 'Data exchange standards and overall interoperability create a robust platform for offsite solutions to develop and eliminate several problems of the past'. The government has to be more active with regards to regulating and structuring the process for Offsite uptake. More specifically, an industry-wide library of standard products or a 'public offsite repository' is needed. ‘It is best not call them 'standard products' but 'parametric components', etc.' because 'standard products' has negative links to it. These libraries should be shared and 'downloaded' to a computer and be made available from projects to projects or company to company. Also, the Government should enable or encourage 3D parametric prototyping to be shared as standard in a pull and use format. ‘Uniclass type resources’ should focus more on Offsite and there is a need for industry Offsite standards and requirements similar to BS/PAS 1192 for BIM. With existing technologies one is able to create a 3D object with manufacturing data and send it straight for manufacturing. Two of the seven key components through which the government articulates BIM Level 2 is the TS3 DfPW and TS3B standard construction classification - as this is a classification issue the BIM Level 2 mandate should resolve it.

A need is also identified for a process guide, which in conjunction with the industry standards should develop into something similar to an ISO, similar to ISO BIM (Bew and Richards, 2013). Albet, 'without specific percentages of Offsite per project, but process focused', it is important to have an 'assurance and accreditation process with set targets and KPIs that industry can work towards'.

The infrastructure market has the advantage of a longevity of programs and therefore it possibly needs the government to step in and help. This can materialise in several ways starting by 'promoting and distilling examples of good practice'. The 'Olympic games' is a great example of a project that was promoted heavily and the industry had access to great 'lessons learned' from its legacy. Secondly, the industry and client organisations need a better structured government investment in research. The most desirable areas for further research identified
were ‘ways to measure efficiency through offsite’ and ‘cost comparison studies between on site and offsite methods of construction’. Finally, ‘the government procurement process is important for enabling offsite’. A model that should be looked into is the automotive industry. This is a reoccurring comparison but ‘this time the focus should not be on the technical elements or the components’, but the procurement process itself. The automotive industry is a supplier focused approach which is very different to the construction industry.

6. Wider Discussion

In parallel to the project focus, organisational focus and support organisation strategies developed during the workshop, a series of interesting debates and discussions occurred throughout the event.

The government’s BIM agenda was often at the centre of the discussions as an initiative that could support offsite implementation, and others as an example of how the industry can innovate rapidly when appropriate actions are taken. One of the points made was that ‘BIM could also pose a great risk to the industry, as CAD was in the early days’. ‘Just because BIM enables one to do something (i.e. complex analysis, simulation, etc.), it does not mean it is right to do it’. This could result in ‘the whole process going the other way and designers could give you an offsite solution with components that may not be the one needed but because they are there easily available’.

Procurement throughout Europe was a topic raised at several stages of the workshop. There was a consensus that ‘there is a need for further work on procurements and contracts to align procurement strategies across the supply chain’. There was many comments about early engagement and how early involvement of the supply chain can enable offsite but there are issues with these ‘approaches’ under current European procurement models. ‘BIM is the enabler for new approach to procurement’ and there are currently several initiatives across Europe ‘hoping to address the issues with EU procurement models and BIM’ which ‘could act as an enabler and further actions could be taken to address the aforementioned issues too’.

Another point discussed was the government’s approach to offsite and setting a minimum offsite percentage per project. Some participants believe that ‘a precise percentage of offsite should be mandated by government similar to the BIM Level 2 mandate’. Others thought that ‘it would be impossible to define offsite’ and therefore apply a precise percentage to projects. In addition, offsite may not ‘add value to all types of projects and therefore it may not be the best option available’. Nevertheless, all agreed that ‘offsite should be connected with the primary government strategy and that it has ‘great export potential not just on offsite solutions and products but also on offsite expertise’.

7. Future Development

![Figure 6 - Offsite hubs now under development](image-url)
Offsite Construction in Infrastructure: 2nd Workshop report

This workshop provided a good platform for clients, industry support organisation and the construction supply chain to engage and discuss together their current perceptions of offsite infrastructure. Following the recommendations drawn during the workshop, a series of offsite hubs are now under development (Figure 6).

In the coming months the aim is to structure and populate these offsite hubs with appropriate experts, not just from the organisations represented in previous offsite workshops but also from additional clients (Highways Agency, Environment Agency, etc.) and supply chain partners (Jacksons, Black & Veatch, HOCHTIEF, Tata Steel, TRL, etc.). The aim of the hubs is to narrow the focus in order to identify best practice and share it across different sectors. During the next workshop, we will focus on developing the terms of reference (ToR), action plan and targets of these hubs for the near future.

8. References

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APPENDIX H  OFFSITE IN INFRASTRUCTURE -
WORKSHOP REPORT 3

Offsite Construction in Infrastructure: 3rd Workshop report

CH2M HILL and Loughborough University
Vasileios Vernikos
Offsite Construction in Infrastructure: 2nd Workshop report

CH2M HILL and Loughborough University
Vasileios Vernikos

Abstract
Offsite construction methods and standardisation is increasingly being seen favourably in the UK by both clients and the supply chain. Many construction industry companies and supply chains see offsite construction as an approach that will reduce costs and construction time, whilst increasing construction quality. Advances in information technology, such as the development of BIM, coupled with supply chain investment in new production processes, are driving forward new thinking in offsite construction. This workshop is the third in a series investigating different strategic actions aiming to increase the implementation of offsite construction processes and solutions in infrastructure. Key recommendations from the workshop were to focus efforts on informing clients (potentially by the formation of an offsite clients group), to increase engagement with the UK government, and to celebrate offsite success through case studies and industry awards.

1. Introduction
CH2M HILL and Loughborough University have been involved in a collaborative research programme focusing on offsite construction for nearly 5 years. At the end of 2013 our offsite construction workshop series was launched with the aim of increasing collaboration and encouraging the implementation of offsite solutions and processes in infrastructure. Building on the success of the 1st workshop ‘Offsite in Infrastructure’ on December 2013, a second workshop was held on May 2014. The 2nd workshop took into consideration the benefits and risks discussed during the 1st workshop and investigated how to develop specific strategies in more detail. The purpose of the 3rd workshop held on October 2014 was to distil the findings of the previous workshops and create a specific plan of action for offsite construction uptake in the industry as a whole. 30 participants from senior management (i.e. director level) were involved, representing major UK contractors, consultants, clients, and industry institutions.

The workshop was divided into the following distinct stages:

1. Initially, the participants were reminded of the findings from the 1st and 2nd workshops. The conclusions were presented to them and they were given a detailed report, outlining both the process followed and the outcomes.
2) Participants were divided into 3 groups containing a variety of members. Each group was asked to identify ‘low hanging fruit’ for offsite construction implementation, areas with the most potential to develop, and areas where offsite is already well developed. Following this, each group presented their findings to the other groups (Figures 1 and 2). Each group’s findings were discussed, and a collective summary was drawn.

3) Using the same process, the 3 groups than produced the purpose, terms of reference and deliverables for the offsite hubs, a key recommendation from the 2nd workshop. The offsite hubs structure, work method, and timeline of outputs for the coming year were all discussed. Following this, each group again presented their findings to the other groups. Each group’s findings were discussed, and a collective summary was drawn.

4) Finally, all of the groups produced a series of focus points that should be undertaken by future workshops, aimed at supporting the industry in helping enable offsite construction. A visual ‘ideas board’ was generated and discussed, and a collective summary was drawn.
2. Defining the Offsite Hubs

The key point emerging from the discussion was that the creation of offsite hubs must not be perceived to have a fixed vision, but rather a direction of travel. The aim of the hubs should be to ‘influence and lead’. One of the most important goals set forth in this workshop was to standardise the key focus of the hubs. The ‘standardisation’ discussed included products, designs and processes. This thought of progression would aim to convince the industry of the practicality of using ‘meccano/Lego’ type components. The end goal should also include the development of ‘product libraries, component focus design’ and ‘mass customisation, which is in library-style components, but with a project-specific approach rather than having a specified target for a % offsite’. ‘This can be only accomplished by having a project-specific offsite plan’.

Participants believed that ‘offsite materials and products exist and are well-developed’. Nevertheless, it was debated ‘whether there is offsite saturation, even in housing, as there is always something to progress and improve’. Albert, as linear assets have repetition, one area that requires improvement is the early industry stage collaborations; in early days of some major rail programmes that may not have been the case, but with updated procurement processes the opportunity and the ability to work with early industry engagement in now more apparent’.

There were also discussions on sector hubs or geographic/regional hubs; participants saw benefits in both, but sector hubs were easier to define. The ‘low hanging fruit’ was new infrastructure programmes such as HS2, CrossRail 2 because there is visibility in the pipeline. This was seen as ‘an easy cut, as it allows the supply chain to invest accordingly’. With a more technical focus, more research and development that will result in ‘quick wins’ include joints of structure, reinforced concrete cages and standardised bridges, as ‘bridges are a great example of offsite and they are iconic for the industry and society’.

The hubs should ideally be composed of a diverse group of industry experts, including representatives from companies, industry bodies and academia, with the relative experience necessary to promote the outcomes of the work. These outcomes can be produced in the form of manuals or guidance reports demonstrating leadership by example and encouraging less IP ownership, and a sharing culture that will feed the industry’s innovative ideas that could be developed further. ‘The hubs should have a core, where the highest level of innovation is conveyed and transferred’. Some of the articles to be published, case studies created, offsite projects delivered, would have to be assigned to the members of the hub’.

These outcomes were proposed to be delivered online in order to enable the broadcast possible access. At that point the concept of WilkBridge was discussed as a good example of offsite standardised innovation that is shared openly in a digital platform. The hubs should also serve to facilitate access to the wealth of data and information already available, which has been identified as not being easily accessible. During this workshop it was pointed out that there are a number of gaps in existing knowledge concerning the benefits that offsite construction can provide. Therefore, the hubs could also help to provide a structure to the wealth of information, which would make the gaps clear, encouraging the participants to focus their attention on specific areas of interest.
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By creating a number of these hubs, competition could be promoted among them, with the best ideas/solutions being given awards in recognition of their efforts. However, cross-hub engagement, openness, trust and exchange of ideas should actively be promoted, as well as the integration of existing hubs working on this topic. Lobbying action can also be taken to achieve government backing for the ‘smart construction hub’.

‘A Government drive is needed in the next 1-2 years, and the hubs should focus at that’. Client organisations stated that they have tried in several different ways to create delivery and operation hubs. Client organisations discussed how the government are keen on BIM and have created a task force and a 2016 target of implementation, supported with significant funding, and have pressured clients to report every quarter on how their BIM implementation plan is developing. ‘Offsite will not work without BIM and is the next step following the BIM initiative’. ‘BIM can provide great metrics that encourage standardisation and offsite construction’. This group should put a business case forward with ‘accurate metrics that justified savings’. Client organisations see possible ‘from the back of these workshops’ the creation of ‘a government-funded task force’ to drive this initiative forward.

Clients thought that the outputs of the hubs should focus on developing ‘a suite of standards and solutions based on 3-Dimensional design, plug-and-play solutions and pre-designed components’. Informed clients are planning the next level of standards which will focus on the ‘metadata’. The hub should be the place to go for all sectors, independently of where the financial backing comes from.
3. Offsite Awards

Another topic discussed is the celebration of success and the recognition of achievements and benefits that offsite construction can bring to the infrastructure construction sector in general. It was proposed that the awards be given following an offsite construction conference that could help set industry standards and provide direction by sharing examples of good practice. These awards will also promote cross-fertilisation and survey the industry for offsite best practice. The award submission will also act as a way to capture and document current offsite projects and practices. The workshop participants also discussed who would be the best people to act as judges and it was agreed that experts from the automotive and aerospace industries should be included, as well as construction. This will encourage non-construction input, raise awareness and standards, and since ‘these industries are seen as leaders in the product-focused design area’ they will be expected to ‘fresh thinking’.

Given the breadth of areas of interest, the workshops’ participants came up with a number of indicative award categories, such as a Technology award, Client award, Delivery partnership award, and an Educational institution award, amongst others.Specifically, one potential award category that provoked discussion was one based on the transfer of knowledge from a different sector, such as manufacturing. The awards could lead to the creation of a best-practice database that the whole industry could rely on for future projects. Following the integration of offsite construction into academic curricula, student papers and projects could also be considered for awards. One example that the industry could imitate is the CIRIA’s Biodiversity awards.

4. Future Development

This workshop provided a good platform for clients, industry support organisations and the construction supply chain to engage and discuss together their current perceptions of offsite in infrastructure. Following the recommendations drawn during the workshop, a series of themes were populated on the workshop ‘Idea board’. The themes were based on the findings of the previous two workshops.
Realising Offsite Construction in the Civil Engineering and Infrastructure Sector

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Vasilios Vernikos

5. Research & Development
When focusing on R&D participants saw the greatest need to 'identify best and worst situations for that adoption of offsite': articulated in a concise way. Secondly was the need to conduct a thorough gap analysis for offsite opportunities that was sector-focused. This should encourage replicability focusing on 'what has been used, was successful and can be re-applied elsewhere'. In addition, a plan is required, focusing on issues such as developing a legal licencing framework, such as creative commons (http://creativecommons.org) to unlock offsite construction to the open source R&D community, developing a ‘Lego’ type solution for foundations and retaining walls using standard components, researching existing case studies and capturing the relevant knowledge and processes, and identifying opportunities for a standardised approach to offsite and to subsequently develop solutions that can be delivered in practice.

Other important issues the workshop agreed that need to be researched included the knowledge management spectrum and the collection of existing case studies, as well as capturing the knowledge to create a commonly acknowledged pool of information. The participants' thoughts addressed the fact that additional research is needed on logistics, delivery and the reduction of temporary works. Regarding materials technology and development, the focus of the research should be aimed at precast concrete connection detailing design and new materials, such as polymers and fibre based additives. All the above could be captured by, for example, 'seeding an Innovative UK (former TSB) programme'.

6. Offsite Metrics & Benchmarking
It was evident from the 'ideas board' that there was agreement on establishing a set of offsite metrics and a benchmarking system. This 'should be done by compiling an accurate set of factsheets and making them publicly available', in addition to setting clearly defined target metrics, such as cost and time (e.g. per meter, per% of design) and charges related to preliminary designs and time spent.

To do this it is necessary to make the existing information and data readily available, while defining a common cross sector strategy. Once again, quantifying the benefits of offsite (such as gains in time, cost, etc.) was highlighted as being important. It was proposed that the government should be involved in the standardisation by base-lining data collection and demonstrating improvements made because of the offsite construction integration.

Figure 4. A group's ideas on offsite opportunities

Figure 5. The ideas board for potential future offsite opportunities
Offsite Construction in Infrastructure: 2nd Workshop report

CH2M HILL and Loughborough University

Vasileios Verniakos

CH2M HILL

The development and use of a widely agreed set of Key Performance based Indicators (KPIs) would encourage clients to procure multiple similar assets through offsite and enable them to compare solutions. Finally, a standardised data capture is required. This could lead to a clear demonstration of tangible wins and losses and how they compare against business as usual.

7. Training & Education
The development of standardised solutions from offsite would require an initial training package, as well as the identification of any potential skills gap and additional training needs. An innovative suggestion was for a firm to sponsor and develop an offsite construction video game to help foster a young community and help bridge the skills gap. It was considered that further work (and a possible case study) is critically needed investigating the effect of changing skills and the reskilling of employees in the industry, possibly in the form of a survey. Engagement should be encouraged on an international level, as well as knowledge sharing and understanding of the current scope of offsite and standardisation. These topics could be covered in education at an academic level, but also additionally in the provision of professional training, such as introducing a short course, and conference style events. These courses (potentially offered by academic institutions) would not be limited to industry professionals, but clients and industry institutions would also be encouraged to participate.

8. Public Engagement Plan
Regarding promoting these initiatives to the public, a commonly accepted vision needs to be agreed upon and all future activities. It was evident that more needs to be done so ‘engineering is promoted as a technology-based profession, leading to increased industry standardisation’. This will also assist in addressing the skills shortage requirements, as well as helping to attract more women into engineering resulting in increased diversity. It would be beneficial if clients appointed communications champions and an industry day set up to communicate findings within the wider industry.

Public engagement is necessary to communicate success and this could be achieved by creating a set of meaningful awards, by introducing awards for best practice, and possibly even a new category at the British Construction Industry Awards. Additionally, another idea put forward during the workshop was the creation of a virtual community space for each project to help communicate long-term value gained by demonstrating the benefits that can be achieved.

Figure 6. Workshop participants populating the ideas board

9. Other Ideas
Additional needs and future developments were captured at the end of the workshop. A dominant need was to create a client-only forum with the aim to set a vision, goals, get homogenous client buy in, and set an agenda. Following this, more work is required in lobbying the government to support the hubs discussed above, particularly the ‘smart construction hub’. This could occur by ‘setting government backing on the back of the BIM initiative’. What would aid this would be to identify a clear business case and funding that would be supported by the government. This should bear in mind sector prioritisation and specifics that include key client timelines and focus areas (CrossRail 2, HS2, etc.). Finally, the participants believed in new procurement approaches that would require the development of a legal licensing framework like creative commons, as mentioned above.

Loughborough University
10. Conclusions

It was evident that the common values of the offsite hubs should be openness and trust. The end goal should be on promoting and encouraging product libraries and common information repositories, 'IT driven innovation, but not an IT exercise in itself'. The hubs should be tasked with creating a robust business case for offsite, aimed at the government. Deliverables should include standardisation through common data sets, and 'asset renewal reminder mechanisms' with a focus on Total Ex instead of Capital Ex. Clients mentioned that 'in many sectors we have 40 year product life cycles, but with 4-5 years funding cycles'. A database of examples that we have already should be identified, information compared, and every member should bring a good and a bad case study of offsite construction. It is important that whatever we do in offsite from now on needs to be recorded and measured, so when it goes good or bad we have evidence-based material to discuss'. The hubs, when created, should not focus at the area of pre-design, these are the competitive stages of a project: 'We should focus at engaging with each other at a pre-project stage, which stage is the non-competitive collaborative space'.

11. References


For more information please contact:

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Head of BIM Development
CH2M HILL
Elms House
43 Brook Green
W6 7EF, London
+44(0)1214560563
+44(0)789865197
## Ethical Clearance Checklist

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has the Investigator read the ‘Guidance for completion of Ethical Clearance Checklist’ before starting this form?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Project Details

1. **Project Title:** Review of Offsite in Civil Engineering

### Applicant(s) Details

<table>
<thead>
<tr>
<th>2. Name of Applicant 1:</th>
<th>Vasileios Vernikos</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Status:</td>
<td>UG Student/PST student/PGR student/Staff</td>
</tr>
<tr>
<td>4. School/Department:</td>
<td>School of Building and Civil Engineering</td>
</tr>
<tr>
<td>5. Programme (if applicable):</td>
<td>Eng Doc</td>
</tr>
<tr>
<td>6. Email address:</td>
<td><a href="mailto:v.vernikos@lboro.ac.uk">v.vernikos@lboro.ac.uk</a></td>
</tr>
<tr>
<td>7a. Contact address:</td>
<td>Flat 1, 208 Avenue Rd, W3 8QQ, London</td>
</tr>
<tr>
<td>7b. Telephone number:</td>
<td>07889855197</td>
</tr>
<tr>
<td>8. Supervisor:</td>
<td>Yes/No</td>
</tr>
<tr>
<td>9. Responsible Investigator:</td>
<td>Yes/No</td>
</tr>
</tbody>
</table>

### Participants

#### Vulnerable groups

<table>
<thead>
<tr>
<th>Vulnerable group</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children under 18 years of age</td>
<td></td>
</tr>
<tr>
<td>Persons incapable of making an informed decision for themselves</td>
<td>No</td>
</tr>
<tr>
<td>Pregnant women</td>
<td></td>
</tr>
<tr>
<td>Prisoners/Detained persons</td>
<td>No</td>
</tr>
<tr>
<td>Other vulnerable group</td>
<td>N/A</td>
</tr>
</tbody>
</table>

#### Chaperoning Participants

<table>
<thead>
<tr>
<th>Will participants be chaperoned by more than one investigator at all times?</th>
<th>N/A†</th>
</tr>
</thead>
</table>
20. Will at least one investigator of the same sex as the participant(s) be present throughout the investigation? | N/A†
---|---
21. Will participants be visited at home? | No

### Researcher Safety

22. Will the researcher be alone with participants at any time? | Yes
If Yes, please answer the following questions:

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>22a. Will the researcher inform anyone else of when they will be alone with participants?</td>
<td>Yes</td>
</tr>
<tr>
<td>22b. Has the researcher read the ‘guidelines for lone working’ and will abide by the recommendations within?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Methodology and Procedures

23. Please indicate whether the proposed study:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involves taking bodily samples (please refer to published guidelines)</td>
<td>No</td>
</tr>
<tr>
<td>Involves using samples previously collected with consent for further research</td>
<td>No</td>
</tr>
<tr>
<td>Involves procedures which are likely to cause physical, psychological, social or emotional distress to participants</td>
<td>No</td>
</tr>
<tr>
<td>Is designed to be challenging physically or psychologically in any way (includes any study involving physical exercise)</td>
<td>No</td>
</tr>
<tr>
<td>Exposes participants to risks or distress greater than those encountered in their normal lifestyle</td>
<td>No</td>
</tr>
<tr>
<td>Involves collection of body secretions by invasive methods</td>
<td>No</td>
</tr>
<tr>
<td>Prescribes intake of compounds additional to daily diet or other dietary manipulation/supplementation</td>
<td>No</td>
</tr>
<tr>
<td>Involves pharmaceutical drugs</td>
<td>No</td>
</tr>
<tr>
<td>Involves use of radiation</td>
<td>No</td>
</tr>
<tr>
<td>Involves use of hazardous materials</td>
<td>No</td>
</tr>
<tr>
<td>Assists/alters the process of conception in any way</td>
<td>No</td>
</tr>
<tr>
<td>Involves methods of contraception</td>
<td>No</td>
</tr>
<tr>
<td>Involves genetic engineering</td>
<td>No</td>
</tr>
<tr>
<td>Involves testing new equipment</td>
<td>No</td>
</tr>
</tbody>
</table>

### Observation/Recording

24a. Does the study involve observation and/or recording of participants? | Yes

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>24b. Will those being observed and/or recorded be informed that the observation and/or recording will take place?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Consent and Deception

25. Will participants give informed consent freely? | Yes

### Informed consent

26. Will participants be fully informed of the objectives of the study and all details disclosed (preferably at the start of the study but, where this would interfere with the study, at the end)? |  |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>27. Will participants be fully informed of the use of the data collected (including, where applicable, any intellectual property arising from the research)?</td>
<td>Yes</td>
</tr>
<tr>
<td>28. For children under the age of 18 or participants who are incapable of making an informed decision for themselves:</td>
<td></td>
</tr>
<tr>
<td>a. Will consent be obtained (either in writing or by some other means)?</td>
<td>N/A</td>
</tr>
<tr>
<td>b. Will consent be obtained from parents or other suitable person?</td>
<td>N/A</td>
</tr>
<tr>
<td>c. Will they be informed that they have the right to withdraw regardless of parental/guardian consent?</td>
<td>N/A</td>
</tr>
<tr>
<td>d. For studies conducted in schools, will approval be gained in advance from the Head-teacher and/or the Director of Education of the appropriate Local Education Authority?</td>
<td>N/A</td>
</tr>
<tr>
<td>e. For detained persons, members of the armed forces, employees, students and other persons judged to be under duress, will care be taken over gaining freely informed consent?</td>
<td>N/A</td>
</tr>
<tr>
<td>Deception</td>
<td></td>
</tr>
<tr>
<td>29. Does the study involve deception of participants (i.e. withholding of information or the misleading of participants) which could potentially harm or exploit participants?</td>
<td>No</td>
</tr>
<tr>
<td>If Yes:</td>
<td></td>
</tr>
<tr>
<td>30. Is deception an unavoidable part of the study?</td>
<td></td>
</tr>
<tr>
<td>31. Will participants be de-briefed and the true object of the research revealed at the earliest stage upon completion of the study?</td>
<td></td>
</tr>
<tr>
<td>32. Has consideration been given on the way that participants will react to the withholding of information or deliberate deception?</td>
<td></td>
</tr>
<tr>
<td>Withdrawal</td>
<td></td>
</tr>
<tr>
<td>33. Will participants be informed of their right to withdraw from the investigation at any time and to require their own data to be destroyed?</td>
<td>Yes</td>
</tr>
<tr>
<td>Storage of Data and Confidentiality</td>
<td></td>
</tr>
<tr>
<td>34. Will all information on participants be treated as confidential and not identifiable unless agreed otherwise in advance, and subject to the requirements of law?</td>
<td>Yes</td>
</tr>
<tr>
<td>35. Will storage of data comply with the Data Protection Act 1998?</td>
<td>Yes</td>
</tr>
<tr>
<td>36. Will any video/audio recording of participants be kept in a secure place and not released for any use by third parties?</td>
<td>Yes</td>
</tr>
<tr>
<td>37. Will video/audio recordings be destroyed within ten years of the completion of the investigation?</td>
<td>Yes</td>
</tr>
<tr>
<td>38. Will full details regarding the storage and disposal of any human tissue samples be communicated to the participants?</td>
<td>N/A</td>
</tr>
</tbody>
</table>
39. Will research involve the sharing of data or confidential information beyond the initial consent given? | No
40. Will the research involve administrative or secure data that requires permission from the appropriate authorities before use? | No

**Incentives**

41. Will incentives be offered to the investigator to conduct the study? | No
42. Will incentives be offered to potential participants as an inducement to participate in the study? | No

**Work Outside of the United Kingdom**

43. Is your research being conducted outside of the United Kingdom? | No

If Yes:

44. Has a risk assessment been carried out to ensure the safety of the researcher whilst working outside of the United Kingdom?
45. Have you considered the appropriateness of your research in the country you are travelling to?
46. Is there an increased risk to yourself or the participants in your research study?
47. Have you obtained any necessary ethical permission needed in the country you are travelling to?

**Information and Declarations**

**Checklist Application Only:**
If you have completed the checklist to the best of your knowledge, and not selected any answers marked with an * or †, your investigation is deemed to conform with the ethical checkpoints. Please sign the declaration and lodge the completed checklist with your Head of Department/School or his/her nominee.

**Checklist with Additional Information to the Secretary:**
If you have completed the checklist and have only selected answers which require additional information to be submitted with the checklist (indicated by a †), please ensure that all the information is provided in detail below and send this signed checklist to the Secretary of the Sub-Committee.

**Checklist with Generic Protocols Included:**
If you have completed the checklist and you have selected one or more answers in which you wish to use a Generic Protocol (indicated by #), please include the Generic Protocol reference number in the space below, along with a brief summary of how it will be used. Please ensure you are on the list of approved investigators for the Generic Protocol before including it on the checklist. The completed checklist should be lodged with your Head of Department/School or his/her nominee.

**Full Application needed:**
If on completion of the checklist you have selected one or more answers which require the submission of a full proposal (indicated by a *), please download the relevant form from the Sub-Committee’s web page. A signed copy of this Checklist should accompany the full submission to the Sub-Committee.

Space for Information on Generic Proposals and/or Additional Information as requested:
For completion by Supervisor
Please tick the appropriate boxes. The study should not begin until all boxes are ticked.

☐ The student has read the University’s Code of Practice on investigations involving human participants

☐ The topic merits further research

☐ The student has the skills to carry out the research or are being trained in the requires skills by the Supervisor

☐ The participant information sheet or leaflet is appropriate

☐ The procedures for recruitment and obtaining informed consent are appropriate

Comments from supervisor:

Signature of Applicant: ........V.Vernikos..........  
Signature of Supervisor (if applicable):  
Signature of Head of School/Department or his/her nominee:  
Date: 22/10/2012
APPENDIX J  INTERVIEW PROFORMA – AN EXAMPLE

Owen Street Relief Road, Tipton
Topics/Areas for discussion
28/03/2011

Details of project
• Parties involved (e.g. BAM Nuttall, NR, Local Council, etc)?
• Value
• Brief technical description?

Definitions
• Off-line? (in-situ vs ex-situ)
• Problems in the industry understanding ‘offsite’ – Discuss
• ‘Under-bridge’ – How do you determine what is a bridge and what a tunnel?

Decision Making
• What other options were discussed (e.g. Bridge-discuss)?
• Advantages and Disadvantages of these options
• What were the clients/NR priorities?
• Why was this option chosen?
• What were the main priorities of the client?
• Were the users (motorists, local citizens) involved? Who?

Practical Challenges
• What risk assessment took place (e.g. settlement of surrounding area, construction risk)?
  Before, during, after?

Industry and Innovation
• What was the approval process for this unique method (with regards to the Council and NR or HA)?
• What were the approval challenges?
• Had you or collaborating companies worked before with the specific Council/NR projects in the past? How well did the parties knew each other (personally) before the commencement of works?
• What do you think helped raise confidence on this method/project?
• Do you think NR or HA is an organisation that promotes innovation? Why?

Knowledge Transfer
• Halcrow worked on the M1 box jacking, at Junction 15, few years back again with BAM Nuttall Ltd. How, Where, at which point of the decision making process, did you find any information available from the previous project? - Discuss

Additional information
• Recommend relevant people to either projects from any of the collaborating parties?
APPENDIX K  ARCOM WORKSHOP : DISCUSSING BUILDING INFORMATION MODELLING AND OFFSITE CONSTRUCTION IN CIVIL ENGINEERING

Reference:

V.K. Vernikos¹, C.I. Goodier¹ and A.G.F. Gibb¹

¹ School of Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU, UK

In 2011, the UK Government mandated that all construction projects (buildings and infrastructure) that they procured would be undertaken within a 3-D BIM (Building Information Model) environment, by March 2016. This has caused both construction procurers and providers to embark on a journey towards universal BIM adoption, including the integration of BIM within a revised construction process. In addition, offsite construction has seen significant development in the building sector in the past decade; however in infrastructure, offsite exploitation has been more limited. This paper presents findings from research into how innovation initiatives such as BIM and offsite can and need to be considered together, thus allowing leaner design, a greater integration of lifetime project data and more novel technical solutions. The analysis outlines the benefits of utilising offsite within a BIM environment, the challenges currently facing the supply chain, and recommendations are made as to how best to implement the emergent benefits.

Key words: Building Information Modelling, Civil Engineering, Infrastructure, Offsite Construction, Innovation

INTRODUCTION

Improving efficiency in construction has been on the agenda of the UK government as well as the industry for many years (Wolstenholme, 2009). Various attempts and initiatives have been documented, addressing different aspects of the construction industry (Simon, 1944, Emmerson, 1962, Banwell, 1964, Latham, 1994, Egan, 1998). Recent initiatives – such as BIM, lean construction and offsite – aim to reduce costs through improved resources and enhanced data management (Vernikos et al, 2011) with BIM becoming increasingly applied within the UK construction industry in recent years. BIM implementation is occurring via a ‘push–pull’ process and BIM is slowly becoming embedded in various forms and methods in many current construction projects (National BIM Report, 2013). The UK government wants to achieve a total of 20% savings of construction costs and aims to implement BIM in all government construction procurement contracts by 2016 (Morrell, 2011) hoping to contribute to the savings target. Many would consider this target to be a real challenge, solely through the implementation of a single innovative initiative, in such a short time.
BARRIER AND DRIVERS


Offsite has been seen to improving efficiency and productivity in construction (Blismas & Wakefield 2007). Drivers of offsite include time, quality, cost and health and safety (Blismas et al. 2006, Gibb & Isack 2003). Despite the existing literature, advantages related to offsite are poorly understood therefore there is reluctance in employing such methods (Pasquire & Gibb 2002). Barriers for offsite are process, value, conservatism and knowledge related (Blismas et al. 2005). Two major issues are the complete understanding of the process and the cooperation throughout the supply-chain (Pan and Sidwell, 2011). According to Nadim and Goulding (2009) improved communication, teamwork and problem solving in critical for increasing the usage of offsite. Many will argue that the construction industry is focused on initial construction cost rather than value, hindering offsite as it is not equitably evaluated (Blismas et al. 2006, Pasquire & Gibb 2002).

<table>
<thead>
<tr>
<th>BIM</th>
<th>Drivers and Advantages</th>
<th>Offsite</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS BIM report, 2013</td>
<td>Profitability</td>
<td>Pasquire and Gibb, 2002</td>
</tr>
<tr>
<td>NBS BIM report, 2013</td>
<td>Time</td>
<td>Pan and Sindell, 2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pasquire and Gibb, 2002</td>
</tr>
<tr>
<td>Kriegel and Nies, 2008</td>
<td>Sustainability</td>
<td>(e.g. Pasquire and Gibb, 2002</td>
</tr>
<tr>
<td></td>
<td>Reduce waste</td>
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<tr>
<td>Nisbet and Dinesenm 2010</td>
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</table>

Table 1: Research summary of drivers and advantages for BIM and offsite

Many of the aforementioned statements can be applied to BIM and its implementation. The drivers and barriers for BIM are not as thoroughly documented as offsite. Table 1 and Table 2 include some of the most critical advantages and disadvantages of BIM currently documented. Recent industry surveys in the UK an USA (McGraw-Hill, 2010, NBS BIM report, 2013) claim that productivity is one of the greatest advantages of BIM. Nevertheless, there is very little evidence, in the literature, for these productivity improvements to have been realised (Whyte et. al., 1999, Taylor, 2007). One may argue that the surveys are more recent and the published literature is outdated. Amongst many barriers documented in the literature the most debated in its effects on cooperation and general communication. There are many (Succar, 2009, Sacks et al 2010) that believe BIM improves communication indirectly through its 3-D elements and visualisations, effectively communicating information on spatial, logistical and material requirements. However, there are others (Ashawi and Faraj, 2002) that argue that BIM does not foster collaboration.
Table 2: Research summary of barriers and disadvantages for BIM and offsite

<table>
<thead>
<tr>
<th>BIM</th>
<th>Barriers and Disadvantages</th>
<th>Offsite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Howard and Bjork, 2008</td>
<td>Process and Management</td>
<td>Blismaz et al, 2005</td>
</tr>
<tr>
<td>Ashawi and Faraj, 2002</td>
<td>Coordination/Cooperation</td>
<td>Pan and Sindell, 2011</td>
</tr>
<tr>
<td>Verheji and Augenbore, 2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nisbet and Dinesenm, 2010</td>
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</tr>
</tbody>
</table>

The civil engineering sector is moving towards a multi-dimensional object-oriented design in a similar way to the building sector.) Many believe that this will inherently encourage the production of ‘objects’ designed for manufacturing, especially if data can be sent directly to the fabricators. Construction is a ‘low information intensity’ industry compared to banking or finance (Hu and Quann, 2005). Nevertheless, structures are complex entities formed by various sub-systems and diverse components. The continued reliance of the civil engineering industry on using paper-based drawings as a means of recording designs and fabrication data is inhibiting offsite innovation. Theoretically, with the ‘digitalisation’ of construction data it is expected that advanced automation in design, manufacturing and erection through BIM will increase offsite (Eastman and Sacks, 2008). BIM is the technology that allows construction data to be ‘machine readable’ and manufacturing of components without human intervention possible (Eastman and Sacks, 2008). Nevertheless, for any technology to be implemented in the industry there is a series of factors to be considered including staffs’ attitude toward the technology, the firms’ structure and culture, the level cooperation between the supply chain partners, leadership and senior management support and the firms ability to change (Iacovou et al, 1995 Irani and Love, 2008)

METHODOLOGY

Grounded theory was applied in this research to allow for insights into investigating the emerging industry processes while avoiding adjusting or steering the data towards previous theoretical frameworks (Glaser, 1998). The grounded theory used focused on a phenomenological approach and deductive derived theory (Strauss and Corbin, 1990). Unlike other qualitative approaches, grounded theory begins focusing on the conceptual scheme through a contextual way avoiding any predetermined theory (Cassell and Symons, 2004). This investigation did not intend to focus on a distinct area but rather to allow the research to unravel through a continuous comparative analysis of incoming data that enabled a conceptual development. The data collection period lasted six months and data was considered sufficient when ‘theoretical saturation’ occurred (Glaser and Strauss, 1967). The conceptual theory was initially established through a series of discussions with industry experts. When the exact research question was identified, a thorough and focussed literature review was conducted including published research, industry reports and government regulations. Twelve semi-
structured interviews were conducted with BIM leaders and directors from leading UK construction contractors and consultants, software vendors, industry institutions and the UK Government. The interviews were thematically analysed.

FINDINGS

Many organisations, academic and industry experts have attempted to precisely define BIM and offsite during the past decade. For this research, twelve experts first explained what each term meant to their organisation. BIM was seen by all as a platform for communication and collaboration. Although the focus is on data and information, attention is drawn to the way the design or modelling processes are managed and controlled. Recurring terms such as ‘correct’ or ‘improve’ show a positive attitude and enthusiasm towards this innovation. To summarise, in this paper, BIM is an umbrella term for object-oriented modelling that relates to both vertical (i.e. buildings) and horizontal (i.e. railway, highways, etc) infrastructure where the objects have extended attributes that can be leveraged to understand the content of a design and allow for a consistent platform of communication throughout the supply chain.

Contradictory, offsite definitions were more diverse. Contractors saw offsite as a construction process, where components are fabricated in a factory or somewhere near-to-site and are transported to site for installation. For consultants, offsite is more of a means to achieve increased efficiency where products, bespoke or off a catalogue, that are manufactured in a controlled factory environment are assembled on-site. There was confusion between the terms standardisation, prefabrication and preassembly.

Past Government Initiatives

Whilst offsite has been promoted by the UK government for generations, albeit using different terms such as prefabrication (Murray and Langford, 2008), the focus on high-powered information and communications technology has been somewhat more recent. In 2002, The Department for Trade and Industry (DTI) combined with the Engineering Physics and Science Research Council (EPSRC) to develop a programme of works, the Innovative Manufacturing Initiative (IMI). The IMI funded a theme called Meeting Clients Needs through Standardisation (MCNS) which orchestrated a group of focused calls for research programmes. The last two programmes funded were Avanti and PrOSPa. Avanti’s core aim was to encourage the use of Computer Aided Design (CAD) by arguing that managing information databases was more efficient than managing ‘drawings in a cabinet’. Avanti supported early access to information from all parties of the supply chain and work protocols promoting improved communication and common information models. Similarly, PrOSPA aimed to encourage offsite solutions across the construction sector (Goodier and Gibb, 2007). PrOSPA was the predecessor to the industry-focussed organisation BuildOffsite and Avanti developed into the BIM initiative.

ManuBuild

ManuBuild was a good example of European funded research on combining BIM type technologies with offsite prefabrication. Briefly, the research team included 22 partners from 8 countries focusing on building concepts from a design perspective and production technology from a construction perspective. The aim of the research was by combining the two processes to achieve an increase sustainability, quality and durability without increasing costs. Some participants interviewed would define the project as ‘one-system-manufacturing, that required standards and component catalogues, automated factories and manufacturing’. Participants in ManuBuild believed that to achieve these efficiencies it was critical to explore how other industries approached similar challenges therefore the automotive industry was explored. Traditionally, the construction industry has 'trouble with precision and efficiency', not as much
with regards to structural design but with time, cost, material usage, man-hours, etc. Model based information such as model driven scheduling and costing was the solution to address the problem. Some issues occurred with large corporate software firms, ‘although they say there are keen to collaborate they do not want to be limited by standards because they see this as making their customer base available to the competition’. Other issues focused on the project management of the research project. The participants interviewed claimed that there are examples of large R&D projects funded from the European Union that have serious issues with project management. The claim that when research in conducted in the construction industry, at least from an industry perspective, the exact outcome or output of the research is ‘unsure’. There is a continuous change of data therefore different targets and expectations. Conventional project managers, which have work of research projects find it exceptionally difficult to work in such a ‘fluid’ research environment. Rigid ideas of industrial partners in research projects create frictions. In cases where there are many partners from the supply chain working on the same research project, the situation becomes even more complex from a project management perspective. There are examples of partners, when under pressure, they become ‘disillusioned and back off’. Partners who are running into difficulties need a particular handling in order to maintain focus and continue to work collaboratively. Participants interviewed concluded that ManuBuild did not have the desired impact to the industry.

BIM and offsite in the Civil and Building Sector

Both Avanti and PROSPA programmes focused their work predominately on the building sector rather than infrastructure (i.e. civil engineering). Despite the downturn in the current financial situation in the UK, offsite is 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 civil engineering sector, but other applications have had little deployment (Gibb, 2001, Goodier and Pan, 2010) and this view was supported by the interviewees in this current survey. Some claimed that the civil engineering sector ‘thinks less of their process and data possibly due to the size and duration of the projects’. Others debated that, in the building sector, learning from project comparison is less challenging as you can analyse, for example, the cost on a functional breakdown and compare the cost of a system from one project to another. Whereas, in civil engineering projects, one cannot compare the contractor’s breakdown neither at a project-by-project basis nor a contractor-by-contractor basis because of its arbitrary nature due to the work breakdown and the different tasks delegated to different sub-contractors on site. Some consultants claimed that offsite was easier to develop for the building sector due to ‘object libraries’ and ‘catalogues of components’.

With regards to BIM, and similarly to offsite, most participants agreed that the building sector is currently leading in its implementation. The main reason was due to the software available being more focused on vertical construction. The software providers interviewed claim that ‘the building sector has instant gratification from BIM and it is less challenging compared to horizontal infrastructure where segmenting the model is a complex process’. Consultants argue that despite software for the building sector being ‘more mature’, the real challenges occur when large geographical areas demand the combined utilisation of Geographic Information Systems (GIS) and BIM. Government experts claim that less research on processes and data transfers is undertaken by the civil engineering sector which ‘lacks comprehensive data systems, such as Industry Foundation Classes (IFCs)’. Although most firms contributing to this research are involved in large scale infrastructure projects, only one participant claimed that ‘some key civil projects (i.e. CrossRail) are using much more superior BIM techniques than any building project’. To conclude, it was evident that the building sector is utilising BIM on a
wider scale and it is more aware of BIM processes (National BIM Report, 2013), however, in civil engineering there are some best practice examples demonstrating the applicability of BIM within a complex infrastructure environment.

All participants agreed that consultants used to lead the way in BIM technologies and methods, ‘starting from a position of strength’, predominately because of ‘their familiarity with the visual aspect of the software and the rapid production of drawings’. During the last few years contractors however have been accelerating their BIM awareness, using BIM as an opportunity to achieve greater savings. In addition, large UK contractors’ main client is the UK government, therefore contractors are ‘forced into rapid BIM implementation’ in order to maintain a competitive advantage. Nevertheless, consultants interviewed claim that contractors use BIM to focus more on the detailed design and the construction phases of the project and less on the operational and the maintenance phases. The UK government representative interviewed highlights the importance of BIM for the lifecycle of the project and claims that the benefits of BIM in the design and construction phases are minimal in comparison.

ANALYSIS

Considering BIM’s effects on offsite, most participants thought that by the UK Government mandating BIM by 2016, the usage of offsite in the civil engineering sector will increase. Some were very enthusiastic, claiming that offsite is the missing link without which there are no easy mechanisms to ensure that design intent is translated into a fabrication intent that is manufactured affectively. In addition, it was claimed that only through BIM ‘one that designs precise digital objects can then fabricate them in factory conditions’. Others were more cautious, stating that there are many parameters that determine where and how to use offsite but ‘BIM helps designers take into account all these factors and make a more informed decision’. Notwithstanding, it was made clear that it all depends on how organisations implement BIM and offsite in the model that they operate. Despite the uniform opinion of most participants that BIM will positively affect offsite, one consultant claimed that BIM does not enable nor hinder offsite because BIM applies equally to on- and off-site work. The consultant believed that ‘offsite is on an upward curve and I don’t think that curve will become steeper since BIM was formally introduced to the industry’.

CONCLUSION

Both BIM and offsite as concepts are not fundamentally new, but terms referring to the ideas have changed over the decades to reflect industry trends. During the past few years a number of successful case studies of offsite within a BIM environment have been published (BIM Handbook, 2011). The majority of them are focused on the building sector with the United States leading BIM implementation. Within the UK, early adopters such as the Ministry of Justice are using BIM with offsite for prison blocks and some ‘best practice’ examples are producing promising results (MoJ, 2013). Despite all the high expectations from the literature and some practical success in the building sector, very limited application of offsite through BIM is witnessed in civil engineering. The participants in this research attempted to identify evidentiary examples to prove that BIM enables, promotes, increases or improves offsite, but apart from some aspects of ‘key infrastructure projects’, no evidence could be provided. The UK Government provided examples where ‘projects started using BIM from the RIBA-Stage C phase and this was deemed fundamentally flawed’. Therefore, based on this principle; some participants’ examples were dismissed as their ‘BIM’ elements were merely 3D visuals or the BIM implementation was encouraged not for its efficiencies but for commercial reasons. When participants were not able to provide evidence they claimed that the statements were going to
materialise during BIM level 3. Nevertheless, as the UK Government confirmed during the interview, currently BIM level 3 is yet to be clearly defined. Offsite is a more ‘familiar’ concept to the civil engineering sector, with precast concrete elements and bridge construction or tunnelling often employing offsite (Vernikos et al, 2012). However, throughout the data collection process many participants confused the terms ‘standardisation’ with ‘prefabrication’ and the term ‘offsite’ was not clearly understood. Economies to scale are achievable through standardising offsite elements and BIM may influence the process drastically, yet the one does not automatically lead to the other. One contractor underlines the distinction claiming that ‘standardisation is an aspect of BIM, but a minor percentage of civil engineering works is standardised’, as parametric and logistical flexibility is needed. With consultants saying that ‘contractors don’t know what they want’ and contractors claiming that consultants give them ‘empty models’ the confusion is not limited to offsite terminology but also to BIM implementation. After analysing the responses of twelve of the BIM and innovation directors representing leading UK consultants, contractors, software vendors and construction industry institutions, it is evident that there is a clear belief that BIM will improve and increase offsite construction in civil engineering. Nevertheless, there is still very little proof that this is currently the case. It appears from the findings presented here that BIM has the potential to improve the quality of existing offsite methods and solutions. This may raise industry confidence and therefore it could indirectly increase the offsite usage overall.

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Realising Offsite Construction in the Civil Engineering and Infrastructure Sector


### Section D – Drivers for & barriers to Offsite

#### 14) What are the drivers for using Offsite in your Civil Engineering sector?

<table>
<thead>
<tr>
<th>Drivers for using Offsite in your sector</th>
<th>Very important</th>
<th>Important</th>
<th>Neutral</th>
<th>Somewhat important</th>
<th>Not important</th>
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<tbody>
<tr>
<td>a. Ensuring cost certainty</td>
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<td>b. Reducing costs</td>
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<td>c. Ensuring time certainty</td>
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<td>d. Reducing construction time</td>
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<td>e. Minimizing on-site disruptions</td>
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<td>f. Increase quality construction</td>
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<td>g. Reducing health and safety risks</td>
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<td>h. Reducing environmental impact during construction</td>
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<td>i. Maximizing environment performance for the lifecycle</td>
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<td>j. Restricted site specific</td>
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<td>k. Addressing skills shortages</td>
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<td>l. As part of company strategy</td>
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<td>m. Client influences</td>
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<td>n. Any other (Please specify)</td>
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</table>

#### 15) Now, considering Civil Engineering as a whole, please asterisk the three drivers above which you think are the most important drivers for using Offsite?

#### 16) What are the barriers to the use of Offsite in your Civil Engineering sector?

<table>
<thead>
<tr>
<th>Barriers to the use of Offsite in your sector</th>
<th>Very important</th>
<th>Important</th>
<th>Neutral</th>
<th>Somewhat important</th>
<th>Not important</th>
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<tbody>
<tr>
<td>a. Complex interfacing between systems</td>
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<td>b. Unable to freeze the design early on</td>
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<td>c. Logistical (site constraints and transportation)</td>
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<td>d. Higher capital cost</td>
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<td>e. Difficult to achieve economies of scale</td>
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<td>f. Risk adverse culture</td>
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<td>g. Client scepticism</td>
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<td>h. Affiliation barriers due to historic failures</td>
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<tr>
<td>i. Lack of long-term cooperation between project</td>
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<td>j. Nature of the UK approval system</td>
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<td>k. Manufacturing capacity</td>
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<td>l. Lack of previous experience with Offsite</td>
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<td>m. Any other (Please specify)</td>
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</table>

#### 17) Now, considering Civil Engineering as a whole, please asterisk the three barriers above which you think are the most significant barriers to the use of Offsite?