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A Note from the Authors

If offsite production and manufacture is to make a positive contribution to both industry and society, research is needed to identify the pivotal issues associated with socio-political and cultural drivers, along with societal, economic and business needs. Given these issues, there is a real need to present a cogent international research strategy which directly addresses design, production and business models theories within the wider context of the industry and supportive supply chain.

This report presents recent developments in research and practice on New Production and Business Models in Construction through the remit of CIB TG74. It highlights the impact of new production models in the Architecture, Engineering and Construction (AEC) industries, and presents these findings from both a developed and developing world perspective.

The following three forwards present an overview of current thinking and innovation drivers associated with the adoption of offsite approaches. The first foreword by Dr Wim Bakens highlights the importance of securing integrated solutions and embedding knowledge from the CIB community. This insight provides a truly holistic view of how tangible solutions can be sourced and successfully delivered. The second foreword by Richard Ogden OBE, presents an industry viewpoint of offsite manufacturing. Buildoffsite is an alliance of clients, developers, designers, contractors, manufacturers, suppliers, government, advisors and researchers. This foreword presents the challenges and benefits of offsite, and highlights the need to create mechanisms for not only increasing awareness, but also establishing viable business models for future uptake. The third foreword by Tom Hardiman, presents the importance of embedding sophistication into the product to not only exceed the expectations of all, but also generate more sustainable designs with improved environmental impact. It also highlights the need for continual research to ensure the industry remains at the cutting edge of the market through the delivery of viable, innovative and flexible solutions.

Finally, the Coordinators would like to thank all the participants and stakeholders involved with the development of this document from both research and practice. This includes all the Task Groups and Working Commissions identified in Table 1, and workshop domain experts identified in Appendix ‘B’.

Thank you.

Jack Goulding and Mohammed Arif
Coordinators of TG74
Foreword 1: CIB The Netherlands

Offsite construction as a concept is not new; but where until recently it was considered primarily a technological and production concept, we now know it will only reach its full potential if it is part of a holistic approach of construction as process, system and business model. Some of the Japanese companies who have applied this approach for a long time now have shown its enormous potential benefits in terms of higher and guaranteed quality, significantly lower costs, substantially stronger reliability and a type of customer participation that was perceivably impossible in traditional construction.

When indeed applied as a fully integrated model, offsite construction has the potential to help our industry evolve into a modern one with a magnitude of customer appreciation architects, engineers and constructors in most parts of the world can now only dream about. Research can help the industry to develop, implement and apply new technologies, process and business models and people skills that will help the integrated model of offsite construction to mature.

The authors of this research roadmap have done a great job in explaining the concept of offsite construction, showing its potential for both the industry and the housing market, describing the way to go and showing how the international experts in the community can contribute.

I trust the research agenda presented in the last part of this research roadmap will inspire and give guidance to decision makers on building and construction research in general, and on the programming and funding of it in particular all over the world. This creates a conceptual platform for all those involved in such research, and who know that through international cooperation the value of their own work may increase significantly.

Dr Wim Bakens
Secretary General CIB
Foreword 2: Buildoffsite UK

The Buildoffsite organisation has been championing the increased use of quality offsite construction methods in the UK for almost 10 years. For sound business reasons an increasing number of clients, designers and constructors are making use of offsite construction methods in order to gain advantage from the faster speed of construction on site, assured levels of build quality and enhanced sustainability that are typically associated with the intelligent use of offsite solutions. Interest in offsite is a global phenomenon and the Buildoffsite network of contacts spans the world. Buildoffsite is committed to sharing knowledge and promoting collaboration in support of innovation in the development and use of offsite solutions. It is recognised that the use of offsite solutions has global relevance, and accordingly, global collaboration is essential if the offsite industry is to flourish. Recently Buildoffsite has participated in an effort by coordinators of CIB Task Group 74 to review offsite construction practices in developing countries including India. The initiative provided valuable insight into construction practices in the developed and developing worlds and has identified opportunities for future collaboration.

Not surprisingly the drivers behind the global interest in the use of offsite solutions are broadly similar in terms of the benefits that offsite can deliver - faster, safer, cheaper and better quality construction capable of being delivered at scale. Other common interests include the elimination of project and commercial risk, a requirement for appropriate skills and competences to meet the needs of the local market and the availability of integrated supply chains capable of working in ways that eliminate wasteful practices to get the best results from the use of offsite components of various complexities. There is also considerable interest in the use of innovative design and production techniques such as Building Information Modelling, Lean Production and Design for Manufacturing and Assembly. There are, of course, a number of substantial differences in the requirements and capabilities between developed and developing markets. Of particular relevance is the scale of the opportunity to adopt innovative construction solutions such as offsite solutions. In India for example there is an almost unimaginable demand for new homes to meet the housing needs of an unmatched shift from rural to urban living. The scale of this requirement is vast and it is essential that practical solutions are found and found quickly. It is axiomatic that traditional forms of construction are not able to deliver the number of homes that India needs within an acceptable timescale, and therefore the need for innovative solutions including the use of offsite methods is both an economic and a social imperative.

Offsite solutions have been in common use for a couple of generations in the developed world and accordingly some considerable element of market maturity and industrial capability has evolved. However, in the developing world awareness of the opportunities for offsite solutions, the need for a supporting infrastructure and the skills and management capabilities necessary to get the best out of offsite solutions are all still in their infancy. Practical imperatives will require the development of technologies, products and skills that connect with local needs and capabilities in order to deliver sustainable solutions.

This report presents an excellent analysis of respective issues between developed and developing markets under the headings of design, construction and manufacturing. The roadmap that has been developed clearly highlights the opportunities and challenges for the future and presents a way forward. The roadmap provides a unique opportunity for practitioners and researchers to advance the development and implementation of offsite solutions to the benefit of all.

Richard Ogden MBE
Director of Buildoffsite, UK
Foreword 3: Modular Building Institute (International Trade Association) USA

For decades, the offsite construction industry has been saddled with the title of “the future of construction,” with no meaningful increase in overall market share. There are many contributing factors as to why offsite has not gained more traction, including a reluctance to embrace new processes from the construction industry as a whole, a fragmented industry composed of thousands of smaller contractors, and the lack of a coordinated effort by industry, academia, and end-user groups to promote and advance more efficient processes. Certain segments of the industry have also struggled with perception issues, often associated with lower quality and durability than traditionally built projects.

Within the past few years, however, many initiatives and efforts have aligned to better position offsite construction to live up to the expectations and begin to change the way the world builds.

Sustainable design and building practices are increasingly becoming the norm in building specifications. The public is more aware and concerned with the negative environmental impacts associated with traditional building practices resulting in massive amounts of construction waste ending up in our landfills. New products, processes and technologies such as building information modeling seem to align more naturally with offsite construction. Building materials have become more sustainable and durable to meet increasingly stringent building code requirements.

Economic pressures have forced owners and contractors to find a more efficient way to build, no longer content with inefficient schedules, inconsistent subcontractor performance, and wasteful practices. And finally, students in schools of architecture, engineering and construction management around the globe are now more familiar with the advantages of offsite construction, and the subject has become part of their coursework. Our association recently spearheaded an effort called “Partners in Education” to facilitate working relationships between the industry and universities to help advance further research and awareness. This initiative has primarily focused on schools in North America, but clearly the need and demand exists on a global scale. But the industry cannot rely on these natural forces and shifts to ensure long term success. There is a great need for continual research to ensure the industry remains on the cutting edge in terms of technology, materials, best practices, and a safe and well trained workforce. To overcome years of misconceptions and to battle an entrenched status quo mentality, the offsite construction industry must provide an end product that is superior to traditional construction in terms of sustainability, durability and performance.

When we stop to consider the global demand for housing and infrastructure, it is impossible to imagine it can be met without a greater use of offsite construction techniques. Offsite construction stands at the intersection of lean manufacturing techniques, sustainable building practices, and advances in the adoption of building information modeling. As the international trade association representing the modular construction industry, the Modular Building institute is thrilled to support the efforts this CIB Task Group.

Tom Hardiman
Executive Director of Modular Building Institute (International Trade Association) USA
1.0 Executive Summary

This report summarises the work of CIB Task Group 74. It presents an overview of the offsite manufacturing market and discusses the key requirements needed for successful adoption and uptake. It presents findings from a three year study, leading to the development of a Prioritised Offsite Production and Manufacturing Research Roadmap. This was created through a series of workshops with domain experts taken from the design, construction, manufacturing and research communities.

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Dr. Wim Bakens (Secretary General)
Professor John V McCarthy (AO Director)
The CIB Board
2.0 Introduction

The CIB commissioned a number of Research Roadmaps to provide authoritative guidance and support for national and international research bodies and funding agencies. Under this remit, a set of core challenges were identified through six core areas (Figure 2.1) in order to identify the pathways needed to establish the future research agenda.

![CIB Research Roadmap](image)

Figure 2.1 CIB Research Roadmap

From Figure 2.1, the Conceptual Framework (①) includes “What are we talking about?”, which includes the main issues, and how these interrelate. This embraces the influences, stakeholders, expertise, characteristics of relevant systems, processes and technologies. The State of the Art (②) includes “Where are we today?”, and includes technology, best practices, international variations and perceived problems. These challenges are extended to include the need for improvement, acknowledging the world’s leading centres of expertise. The Future Scenario (③) covers “Where do we want to be in 10 year’s time?” and gauges stakeholders opinions on required/envisaged future systems, processes and technologies, including preferred future practices (and corresponding skills needed). The Development Strategy (④) includes “What is needed in terms of knowledge, information, tools, concepts and applications?”, in order to enable the respective systems, processes and technologies to develop from where we are today to where we want to be in ten years. The Research Contribution (⑤) includes “How can research contribute to such development strategy?”, noting the main requirements needed for research to make that contribution. Finally, the Research Agenda (⑥) covers “What is needed for the worldwide research agenda?”, which includes areas of science and technology development, the required sequences, priorities and international cooperation needed between research and practice communities to make this happen.

Given this remit, this document presents an overview of the main concepts and issues explored by TG74 (New Production and Business Models in Construction), culminating in the development of a prioritised offsite production and manufacturing research roadmap and supportive future research strategy needed to underpin and deliver this.
3.0 Offsite Manufacturing

3.1 Current Overview
Modular building as both a concept and initiative is being adopted across both developed and developing countries. Whilst it is acknowledged that the level of adoption, absorption and diffusion varies from country to country, the various challenges associated with uptake are somewhat constant (albeit subject to context-specific priorities). For example, in the developed world there is a need to produce quality ‘affordable’ housing stock that meets the needs of society. This not only includes conformance to certain standards and performance criteria, but also compliance with environmental and sustainability criteria and legislation. Whereas, from a developing world perspective, similar challenges prevail, albeit with a slightly different emphasis being placed on producing mass low-cost housing. Given these broad challenges, offsite manufacturing has been acknowledged as being a way of meeting these needs. For example, the Construction Industry Council (CIC) in the UK noted that the modular building approach offered several benefits over traditional approaches, not least:

- higher sustainability standards
- better build quality
- faster speed of delivery
- improved construction health and safety
- enhanced energy-in-use
- lower whole-life carbon footprint
- reduced transport pollution (congestion and emissions)

(CIC, 2013).

Whilst these benefits are significant and tangible, the uptake of offsite manufacturing across different economies worldwide varies considerably from country to country. One of the factors that has influenced this in some countries is the preconceptions held by some parties and end-users. For example, in the UK, the Housing (Temporary Accommodation) Act 1944 was used to deliver the housing shortage post World War II using temporary prefabrication methods. These homes had a predicted lifespan of 10 years, and consequently, the quality suffered in some instances. Whilst this perception still pervades thinking today, somewhat ironically, there are several of these prefabricated homes still in existence today. Similar initiatives in the USA post 1945 developed the “Lustron home”; but earlier examples of prefabrication can be seen through the “Sears Modern Homes” circa 1908 (which used a ready to assemble approach or “kit house”); and even earlier around 1837 in Australia, where prefabricated homes were imported from the UK, USA and Singapore. Offsite manufacturing is therefore not a new concept. It is increasingly being seen as a viable approach for delivering high quality innovative solutions that embrace cutting edge design, and which meets or exceeds the highest levels of performance and sustainability criteria.

3.2 Levels of Offsite Adoption and Uptake
The adoption and uptake of offsite construction has continued to show steady growth across a number of dominant markets – particularly in Japan, Malaysia, USA, UK and Australia. However, the overall percentage of offsite construction to traditional construction approaches is still low. For example, in the UK the market share is around 6% (Taylor, 2009), 7% in the USA (HAC, 2011), and around 20% in Japan. Whilst the higher percentage uptake in Japan may be linked to other factors (e.g. extended warranties); the overall impetus for this growth across the global sector as a whole is promising. This is due to several
interrelated factors, not least: new quality thresholds, improved customer perception, the introduction of governmental support initiatives, and through the success of various high-profile case studies. For example, in the USA standards and codes have been designed to regulate manufactured housing design and construction (see the Manufactured Home Construction and Safety Standards Act in the USA in 1976, 42 U.S.C. sections 5401-5426, also referred to as the HUD Code). In the UK, influential reports such as Egan (1998) and the Offsite Housing Review (2013) noted the importance of further investing in offsite as a viable business model. Similarly, in Australia manufactured housing is seen as a major part of development plans (Hampson and Brandon, 2004; Blismas, 2007). Whereas, in Malaysia the Construction Industry Development Board has established formal legislation for offsite provision, which is supported by an Industrialised Building Systems Centre (CIDB, 2013). This is a mature market with a clear and established supply chain. The offsite provision in China is also developing at a steady rate, with several opportunities being evidenced (Arif and Egbu, 2010).

Given these indicators, it is important to identify and examine the socio-political issues and accompanying forces (e.g. culture, societal drivers, economic/business models etc.), that not only affect the successful adoption and uptake of offsite per se, but equally, to examine the interrelated disciplines [Construction/Manufacturing/Design] as a whole in order to maximise future opportunities.

3.3 Skills Requirements

The development of skills within an organisation is probably one of the most important issues needed to effectively manage and deliver the core business. Skills can therefore be seen as the key differentiator of one company over another – the competence of which is also often referred to as “intellectual capital”. It is therefore important to appreciate that these skills will need to be constantly updated in line with changing business imperatives. Given the potential of moving from a traditional ‘construction’ environment, into one which embraces offsite manufacturing, this transition will often require a paradigm shift in thinking. For example, offsite manufacturing has different processes, technologies, production techniques etc. Therefore, new skills will be required to deliver this new way of thinking and approach to business. The manufacturing and design industries have a lot to offer here. Skills are therefore needed to effectively manage the interface between traditionally constructed elements and offsite elements (Nadim and Goulding, 2011).

The term “modern methods of construction” covers a range of options, from volumetric through to hybrid systems. Given this definition, the provision of skills need to embrace the silos of other disciplines in order to maximise their overall effectiveness, as the roles and responsibilities of different parties need to be fully embraced and understood (NHBC, 2006). For example, in an advanced manufacturing environment, emphasis tends to be placed on mechanisation, robotics, logistics, handing, quality control etc. Therefore, reliance on skills is ostensibly contained (and controlled) within this sector-specific silo. Similar analogies apply in the design and construction sectors. Integration therefore becomes an important part of skill development. In the UK for example, ConstructionSkills and the Sector Skills Council for the construction industry openly acknowledge the need to provide training, education and development needs. The

Offsite construction requires new skills in:
- Design for manufacture and assembly
- Production engineering and process efficiency
- Purchasing, planning, and materials handling
- Project integration and multi-skills

(CIC, 2013)
importance of up skilling through training to overcome skills gaps is therefore important (ConstructionSkills, 2008; CITB, 2011; Blismas and Wakefield, 2009; Sadafi et al, 2012).

From an offsite manufacturing perspective, there have been a number of attempts to provide this training in such areas as new manufacturing concepts and processes using a number of initiatives. These include the Building Management Simulation Centre (de Vries et al, 2004), the ACT-UK Simulation Centre (2013), and bespoke virtual reality simulators focussing on offsite (Goulding et al, 2012). Skills can be developed using these approaches to ‘engage’ learners in decision-making roles - ‘pushing’ them through ‘unpredictable’ challenges to proactively promote learning through direct interaction and feedback, using real world contexts to address such issues as: late design changes; loss of factory production/capacity and unforeseen external factors (Goulding, and Pour Rahimian, 2012). These issues are increasingly important; for example, the need to understand how Design for Manufacture and Assembly (DIMA) affects project delivery and the purchasing cycle. Similarly, it is important to engage the appropriate skills to new technical developments such as Building Information Modelling (BIM) and advanced Enterprise Resource Planning (ERP) approaches.

3.4 Technology and Manufacturing Requirements
The rate and pace of technology continues to provide tangible business benefits for the manufacturing sector. However, the construction industry (compared to other industries) has not yet been fully successful in using this technology for offsite manufacturing – particularly for information flow, materials and labour management, waste etc. These limitations are well known. Therefore, in order to meet the existing and emerging demands required for offsite construction, the adoption and application of cutting-edge technologies are needed (Taylor, 2009; Nadim and Goulding, 2011; Stewart, et al, 2003; Goulding et al, 2007; Krar and Gill, 2003). Given this, technology should not just be seen in isolation as it needs to be evaluated in context with the wider organisational requirements, environmental issues, and business imperatives (Smith, 2011). The interrelationship between the dynamic nature of business and the supporting infrastructure can therefore best be described through the technology-push v demand-pull model (Alshawi, 2007). In addition, information and communication technology (ICT) has openly revolutionised production and design (Cera et al., 2002) which has led to advancements in terms of production materials and labour (Fruchter, 1998). Therefore, adopting a cognitive approach to design can often improve development processes and improve collaborative working across construction - leading to improved outcomes and better design. However, further advances are still needed in virtual prototyping systems, as these are still not ‘smart’ enough to cope with the increasingly complex and dynamic nature of construction projects (Tah, 2012).

From a holistic perspective, design, construction, as well as manufacturing and onsite application techniques are now becoming more intelligent, integrated and automated (Akintoye et al, 2012); and offsite manufacturing, along with ICT for construction and virtual prototyping are at the forefront of technological needs: 

- New collaborative design teams
- Specialist assembly approaches
- Proven modularisation techniques
- New skills

‘Smart’ technological solutions need:
advances supporting modern methods of construction (Pour Rahimian, 2012). Whilst new developments in additive manufacturing (Lim et al. 2012) show promising results for use in offsite; the emergence of BIM also seems to offer many potential technological solutions, especially where it additionally supports construction information at various stages of the project lifecycle (Gu and London, 2010). The importance of BIM stems from having an open interchange of information across platforms and a transferable record of building information throughout the life cycle of a building (Isikdag et al, 2012). Technology allows the project team to plan out how every single aspect of a building will be created. This has the potential to have a significant impact on off-site construction. However, the ultimate success of BIM will in part depend on the ability to capture all relevant data in the BIM model, and to successfully exchange data between different project participants (Nawari, 2012). More fundamentally perhaps, it is equally important to acknowledge the impact of e-readiness (Goulding and Lou, 2013), as in the context of ICT, organisational capability embraces many facets, not least skills, flexible management structures, well-articulated processes and clear business goals, but also the appropriation of an advanced ICT infrastructure aligned to corporate goals (Tah, 2012; Ahuja et al, 2010; Brewer and Runeson, 2009).

Offsite manufacturing presents a raft of challenges and opportunities for new entrants. The challenges in particular seem to deter some organisations from making this transition due to: the perceived infrastructure changes needed, level of change required at company, and the associated level of investment required. However, in many cases these issues can be ameliorated through careful business planning, the engagement of specialist supply chain partners, and through process restructuring (to align existing processes to manufacturing processes. Moreover, simple staged transitional (phased) arrangements can often be more effective than major implementation plans. Blisma et al (2005), categorised these constraints into four main areas: 1) process 2) value 3) supply-chain and 4) knowledge constraints. It is important to consider these four areas, as there are many opportunities that can be leveraged from each. For example, consider the first area of “process”; where Winch (2003), noted that it was important to consider the models of manufacturing in the construction process. Moreover, there has been a significant amount of research undertaken on the application of lean principles to process (Alarcon, 1997; Forbes and Ahmed, 2010), and several areas of improvement can be identified – especially to reduce or eliminate non-value-adding flow activities. Cost and value are key learning points here (Thuesen and Hvam, 2011). Furthermore, combining the strengths of the modular approach with lean construction has the potential to improve sustainability (social, environmental, economic etc.) with tangible outcomes (Nahmens and Ikuma, 2012). However, specific care and attention should be noted here regarding the ‘silo’ approach to adoption [verbatim], as in some cases “it has not been possible to transfer radical managerial innovations, such as lean production, from manufacturing to construction at a theoretical level” (Koskela and Vrijhoef, 2001). On the same theme of “process”, initiatives in Concurrent Engineering (CE) have been widely implemented in the manufacturing industry, with notable benefits in: reduced product development times; improved product quality through the early consideration of life-cycle issues; and the systematic incorporation of customer requirements in the product development process (Anumba and Kamara, 2012). Moreover, for CE to work, it is fundamentally important to examine the concurrent environment, components, and teams involved in some detail (Prasad, 1996). Both CE and lean principles rely on integrated teams working on robust project development processes, supported by a clear strategy which outlines the expectations and responsibilities of all parties. These approaches can be directly applied to modular building and advanced manufacturing techniques.

3.5 Innovation Drivers
Innovation has often been acknowledged as a fundament part of product and process improvement. As a practical concept, it can be considered as being subtle, incremental or radical. Given these distinctions, it
is important to note that several definitions have been proffered for innovation. For example, Van de Ven (1986) regarded innovation as any ideas, practices and technologies perceived to be new by the organisation involved. Whereas, Slaughter (1998) defined innovation as the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change. Similarly, Stewart and Fenn (2006) described innovation as the profitable exploitation of ideas. These definitions all have one underlying common denominator, they all aim to successfully develop or implement new ideas, products, process or practices to increase organisational efficiency/performance (Egbu et al., 1998, Ling, 2003, Sexton and Barrett, 2003; Panuwatwanich et al., 2009; DTI, 2003). Given these dimensions, a number of significant innovation opportunities can be successfully leveraged using appropriate infrastructure and support mechanisms (Akintoye et al., 2012).

Offsite manufacturing has the potential to instil a paradigm shift in current thinking – which in turn can be used to leverage innovation. Moreover, developing innovation and learning from other industries such as ‘manufacturing’ is not a new phenomenon (Nadim, 2012; Womack et al., 2007; Gann, 1996; Egan, 1998; Höök and Stehn, 2008; Latham, 1994). The real challenge here is to harvest innovation in such a way that competitors would find difficult to emulate. This resonates with Winch’s (1998) view of “complex product systems”, and being able to manage two key innovation dynamics i) the top-down adoption/implementation dynamic, and ii) the bottom up problem solving/learning dynamic. More fundamentally however, it is equally important to consider the importance of technological developments in Building Information Modelling (Nawari, 2012), Virtual Reality and the need to provide multidisciplinary training and education (Nadim, 2012; Goulding et al., 2012).

The opportunities to exploit manufacturing innovation drivers include several areas, not least:

- New supply chain relationships
- Robotics and advanced production technologies
- Design for Manufacture and Assembly
- Fully integrated product delivery (IPD) processes
- New skills and tacit knowledge
- New business models (environmental/sustainability, production/logistics etc.)

3.6 Summary
The adoption and uptake of offsite manufacturing is continuing to provide steady growth. However, whilst this still only represents a fraction of the market available, there are increasing signs that this is changing. Given this inertia, it is important to consider the key factors associated with business success, especially when deliberating market penetration. The main concerns centre on niche provision, that is, product differentiation. Whilst market dominance exists in some countries, this can not be said for all. The opportunities are there to exploit, especially in the provision of skills and products to meet market demand. More specifically, a number of innovation opportunities exist for companies wishing to leverage technological solutions. In particular, these include such issues as DIMA, IPD and BIM.
4.0 State of the Art

4.1 Introduction
Manufactured construction, off-site construction, off-site manufacturing, industrialised building systems and modern methods of construction are all terms that have been used interchangeably to describe prefabricated construction. However, the primary intent of prefabricated construction is to move some or all of the construction site activities into a ‘controlled environment’ - typically a manufacturing or factory facility (Arif and Egbu, 2010). The main reason for this is to garner several benefits, not least: a higher speed of construction, improved quality, lower costs and lower labour requirements on-site. Given these benefits, it is also important to acknowledge how best to integrate business processes at the organisational level to foster organisational learning (Pan et al, 2012).

Although several studies have advocated the need to promote Industrialised Building Systems (IBS) (Taylor, 2009; Nadim and Goulding, 2009; Gibb and Isack, 2003; Kazi et al, 2007), currently, IBS only contributes a very small proportion of construction activity in both developed and developing countries. The following sections provide a synopsis of current offsite manufacturing developments and initiatives being undertaken in various parts of the world.

4.2 Australia and New Zealand
The uptake of offsite manufacturing in Australia and New Zealand has been steady and sustained. For example, the Australian construction industry has recognised that offsite should be a part of the overall vision to improve the industry over the next decade (Blismas, 2007; Blismas and Wakefield, 2009). The offsite sector covers a range of clients, from supplying mass housing for mining camps, through to the provision of bespoke specialist high-end custom built houses. Three key streams of research have been developed to improve the perception and willingness to adopt offsite manufacturing in Australia through: ‘case study’ approaches; ‘added-value’ approaches; and the application of manufacturing principles to construction. These are going some way to improving the image of modular building. Through a similar initiative, New Zealand has acknowledged the importance of offsite for delivering genuine benefits through innovation, improved efficiency measures, and streamlined building processes (Schofield et al, 2009). In addition, a prefabrication roadmap has been developed for 2013-2018 (Prefab, 2013).

By the year 2020, there will be more and more off-site automated production, less skilled site trades, more prefabrication, pre-finished elements and products.

(Hampson and Brandon, 2004)

These issues resonate with findings by (Hampson and Brandon, 2004), who highlighted such benefits as improved productivity, reduction in construction time, simplification of construction processes, higher levels of quality, better consistency and testing, lower overall costs, improved working conditions, less skills shortages, fewer interfaces, improved waste reductions, and higher energy performance. However, two major issues of concern were highlighted, specifically: marketing and communication, and research and development. Marketing and communication is seen as being the key for addressing client scepticism, whereas research and development is needed to move the industry forward though such initiatives as education, training and skills development.
4.3 China
There is growing interest in offsite construction across China, especially through existing well-established supply chains evidenced in such areas as gas, oil and mining. However, this is still a relatively new market for housing, and offsite adoption and uptake represents only a fraction of the market available. That being said, a number of large companies have established offsite relationships with companies outside of China – from the manufacturing and supply of simple modular components, through to the provision of complete housing units. Given this, China has not only the potential to exploit its own internal market, but also to open up new markets in other countries. Current thinking seems to be constrained by a reluctance to adopt modularisation and prefabrication techniques – possibly due to a number of factors, including lack of understanding of the potential benefits, or misunderstanding the risks.

Exporting the products of manufacturing has been a key component of China's expansion; especially with its vast manufacturing capacity and relatively low labour costs; this offers the potential for an attractive future market in manufactured construction (Arif and Egbu, 2010). However, future success will need to harvest the wider synergies from more mature markets in order to fully exploit this potential. This includes embracing the design, construction and manufacturing industries tacit knowledge, along with embedding the aspirations of governmental drivers. This is not only an intrinsic need, but also a fundamental necessity. It is therefore advocated that by strengthening international and collaborative relationships, China will yield significant benefits. This should then cascade through the wider offsite industry and be diffused into other countries. The launch of “Prefab China 2013 - Prefabrication and Modular Construction China 2013” exposition (Prefabication and Modular Construction China, 2013) is a significant step forward in this respect.

4.4 European Union
The European Union (EU) construction sector is one of the largest industrial employers, encompassing more than 2.4 million enterprises and approximately 14 million employees. This represents a Gross Domestic Product contribution of around 9.9%. However, this has faced several challenges over the past few years, not least, poor performance compared to other sectors/industries. Acknowledging this, several initiatives have been established to develop a more “knowledge intensive” industry, which aspires to embrace new concepts developed by other industries including manufacturing, automotive and the aerospace sector (ECTP, 2005). Recognition has been placed on acknowledging that advanced manufacturing techniques must be introduced either on- or off-site to enable suppliers and manufacturers to: reduce costs; enable mass customisation; reduce installation problems and associated health and safety risks; facilitate better design; and improve overall quality and consistency. The emphasis is to reengineer construction processes by learning from others in order to maximise flexibility, deliver innovative solutions, and transform the sector into a knowledge-rich environment which offers new business opportunities. This includes the development of new industrialised construction processes and production technologies adapted from the manufacturing industry. On this theme, a €10m research project was part-funded by the EU under its Framework 6 programme (2005-2009) to start addressing some of these challenges. This four year industry-led project involved 24 partners across 10 countries in Europe, and focussed on delivering a radical breakthrough from its predominantly craft/resource-based approach to construction, through to an ‘Open Building Manufacturing’, approach which combined ultra-efficient (ambient) manufacturing approaches from a manufacturing environment (www.manubuild.net) - where “The
The vision of ManuBuild is open building manufacturing, a new paradigm for building production and procurement by combining highly efficient manufacturing techniques in factories and on construction sites and an open system for products and components offering diversity of supply and building component configuration opportunities in the open market” (Boudjabeur, 2006). Research deliverables included developing a range of new manufacturing technologies and logistics solutions, through to new rapid assembly connectors, and an advanced virtual reality training simulator for offsite manufacturing.

Other initiatives in the EU include Sweden, where the offsite market is well-established; with some companies extending lean principles to leverage improvement initiatives (Melling et al, 2012). Similar mature production supply chain networks exist, not least in Norway, Finland, Poland, Austria, the Czech Republic, Germany and Spain.

4.5 India
The Indian economy is rapidly expanding; there is also a growing demand for housing. This presents several opportunities for offsite adoption, especially to meet the housing shortfall (approximately 26 million homes needed). There is such significant demand for new housing in India that the Indian Government and construction/manufacturing industries are now embracing a range of mechanisms as a means of producing high volume, high quality homes as efficiently as possible (RICS, 2010). From a market penetration perspective, India has an established offsite and modular construction community, the maturity of which is steadily developing; this having originally started around 1950 with the emergence of the Hindustan Housing Factory. However, whilst the term “prefabrication” has become synonymous with durable, modern, and western construction methods, the adoption of offsite in the Indian sector is still very low. This may be due to several reasons, not least because “Prefabrication technology has not transferred as easily when compared with other technologies because it is a production technology or knowledge based and not a consumption technology or product based” (Smith and Narayanamurthy, 2008).

Early adopters of offsite in India are aware of its potential to support core sustainability objectives (Sandhir, 2011). Additionally, what is being produced through offsite is generally seen as being cost effective, quick-to-assemble and sustainable. However, the levels of automation and manufacturing available in India may be acting as an inhibitor. Moreover, it is apparent that the accompanying supportive infrastructure needs to develop in order to help this market grow. This needs to be underpinned with a critical mass of conjoined skills across the whole supply chain to fully embrace these challenges in an integrated way. This includes the provision of appropriate regulatory bodies, to not only help ensure quality, but also create opportunities for leveraging innovation through product variance and segmentation. Given these issues, the industry as a whole recognises these opportunities and the transitional path needed.

4.6 Japan
Japan is currently the world’s largest practitioner of manufactured construction, with some companies producing over 70,000 manufactured homes a year. This is a very mature market, with several large companies including Toyota Homes, Misawa Homes, Sekisui Homes, and Sanyo Homes being well-established. These firms are able supply customised homes which are pre-assembled from standardised
components or modular systems (Barlow et al., 2003). Prefabrication is seen as a medium to high-end product, and prefabricated homes constitute approximately 20% of the domestic market. However, there are specific contextual issues to acknowledge in Japan, the most prominent of which is the high building density and limited available land for development/redevelopment. Redevelopment cycles are also quite short (approximately 30 years), which makes the house building sector quite buoyant. As a result, Japan has been in a strong position to make positive developments in adopting modular building to meet residential demands and the change in emphasis on sustainability drivers.

### 4.7 Malaysia

Offsite manufacturing in Malaysia is very well developed. It has a mature market and support infrastructure which envelops the whole supply chain – from users, through to consultants, contractors, and manufacturers. Malaysia first began to use IBS in the early 1960’s when the Government started its first project. The main focus was to improve delivery times, whilst also producing affordable and quality houses. The Construction Industry Development Board (CIDB) of Malaysia was established in July 1994 under the Construction Industry Development Board Act (Act 520) to coordinate all activities in the construction industry in order to increase overall competitiveness. Through this, various initiatives have been created, including an IBS Centre and a new IBS Roadmap for 2011-2015 (CIDB, 2013) which focuses on a) good quality designs, components and buildings, b) completion times, management and predictability, c) availability of component IBS professionals and workers throughout the entire project lifecycle: from design, manufacture, build and maintenance, and d) to evaluate financial stability. This roadmap covers the IBS user, IBS product, and IBS industry; and has two main goals:

1. To sustain the existing momentum of 70% IBS content for public sector building projects through to 2015
2. To increase the existing IBS content to 50% for private sector building projects by 2015

Awareness, information and motivation are key to driving forward the adoption and uptake of offsite in Malaysia. This includes the active engagement of the industry at strategic level, which promotes and encourages knowledge sharing. This is underpinned by a series of comprehensive training programmes which use both public and private construction training centres – the provision of which is supported by offsite product catalogues and bespoke design guides.

### 4.8 North America

The offsite market in North America is very sophisticated and is supported by a comprehensive supply chain - where “Modular manufacturers are located throughout North America, with larger “clusters” of manufacturers in Pennsylvania, Georgia, Texas, Indiana, California, and Alberta, Canada….. and … most manufacturers in North America are single-location operations and can competitively transport units within a 500-mile radius of their plant” (Modular Building Institute, 2011). This market embraces both permanent modular construction and temporary relocatable buildings. The prevalence of modular manufacturers has
evolved, creating a very mature market – the work of which is supported by an increased need to openly demonstrate a range of efficiency measures, not least improved productivity, lower costs, faster completion times, and the ability to create sustainable and flexible solutions (Hardiman, 2012a; 2012b). The Modular Building Institute is the main body for offsite in the USA, with over 200 members across 15 countries – work of which is also aligned to several initiatives, including the Green Building Council’s LEED programme.

In summary, there is strong industry support across North America and Canada for modular building. It is anticipated that by the end of 2013, 98% of the sector will be using prefabricated construction in some form. This includes housing, healthcare projects, higher education, low-rise office developments, public buildings etc. The barriers to adoption include misconceptions around the quality of modular buildings and a general lack of awareness of the benefits that offsite can bring to a project. From a technology perspective, North America and Canada are openly exploiting technological solution such as BIM and ERP on a regular basis. This trend is continuing to rise, with approximately 78% of prefab/modular adopters using now BIM on some projects (McGraw-Hill Construction, 2011).

4.9 United Kingdom

The first known implementation of offsite dates to around 1850 with the construction of Crystal Palace in London. Whilst this market has been somewhat cyclical, particularly after the First and Second World Wars, there was a second movement towards industrialisation in the 1950s and 1960s, and a further growth in uptake of volumetric or modular construction around the 1970’s (Taylor, 2009). The Egan report (Egan, 1998) was instrumental in promoting the need for offsite as a way to improve productivity. This market is now very mature, with a number of influential clients, designers, manufactures and contractors actively promoting offsite. Given this, Buildoffsite is the major industry body championing the greater uptake of offsite in the UK and overseas. Its mission is “to bring about a step change in the exploitation of offsite applications in construction” (Buildoffsite, 2006). The Buildoffsite work programme has been developed to deliver the following objectives:

- To promote increased awareness of the business case for the increased use of quality offsite construction solutions for all market sectors;
- To provide information and services that will encourage clients, constructors and other decision takers to be better informed regarding the opportunities to increase their use of offsite solutions as a construction method of choice;
- To act as a focal point for the sharing of knowledge and best practice on the use of offsite solutions;
- To work to eliminate any negative perceptions regarding the use of offsite solutions;
- To provide services to the Membership that will deliver tangible commercial value; and
- To promote the offsite value proposition to Government, leading industry professional bodies, insurers and other influencers.

(Buildoffsite, 2012).
Whilst significant milestones have been identified concerning the need for further offsite adoption (Pan et al, 2007), a recent offsite housing review report on the use of offsite construction noted a number of major benefits, including: predictable performance; improved sustainability; reduced construction time; improved working environment; fewer sub-contractors on site; reduction in vehicle movements on site; reduced impact of poor weather; fewer construction defects; and a reduction in waste of materials (CIC, 2013). Technological solutions are also widely used in offsite; where BIM-enabled ‘design for manufacture and assembly’ (DFMA) and ‘lean’ construction processes are raising the bar for process/product efficiencies (HM Government, 2012).

4.10 Summary
This overview presented a synopsis of the current offsite manufacturing developments and initiatives being undertaken in various parts of the world. Whilst acknowledging that these markets differ in size, level and overall maturity; it is encouraging to report similar levels of inertia and support for offsite in general. However, it is equally important to recognise the need to formally improve the overall adoption and uptake of offsite. Whilst several opportunities have been discussed, securing innovation is seen as the next major opportunity for exploitation.
5.0 Conceptual Framework Development

5.1 Introduction
The premise behind the development of a new conceptual roadmap for offsite stemmed from the increasing need to provide a coherent set of priorities and indicators for the construction, design and manufacturing industries (Figure 5.1). These three industries are well established, and in many respects, are interrelated and integrated. The overlapping central core “offsite” identifies the potential for exploiting synergies in offsite, particularly the changing needs of the core offsite business as a whole – taking into consideration market maturity and the rising new innovation opportunities evidenced in this area.

![Figure 5.1 Design, Construction and Manufacturing: Offsite Interrelationships](image)

This research is aligned to the CIB priority themes, and can be marched against some of the Task Groups, and Working Commissions. Given this correlation, the TG74 research agenda focussed on the identification of four priority research targets, to address the main deliverables; these being: 1) People; 2) Process, 3) Technology, and 4) Innovation. These priority targets are key themes arising from government reports, high level initiatives, research foundations, funding bodies, extant literature etc. – the specifics of which were confirmed though the work of this task group. More fundamentally, these targets were also seen to resonate with issues being undertaken in various other CIB Task Groups and Working Commissions at both micro and macro levels (Table 5.1); the process of which was used to evaluate the impact relationships, overlaps, and similarities in order to secure authoritative guidance and good practice prior to undertaking work in this area.
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Table 5.1. Relationship of TG74 Priority Targets to CIB Task Groups and Working Commissions

5.2 Development Approach
TG74 adopted an ‘open ended’ approach for the development of a prioritised offsite production and manufacturing research roadmap for offsite construction. It was considered important to establish a roadmap that could be not only used from a geographically neutral standpoint, but also from a context or region-free basis (cognisant of socio-political and economic drivers, regulatory or financial support mechanisms, level of market maturity etc.). Therefore, the development process for this roadmap was divided into two discreet stages. The first stage was used to define the outline structure of the roadmap. This included populating the framework with issues deemed important from stakeholders representing
developed markets from Europe, North America and Australia. The second stage of the development process used representative stakeholders from a relatively immature offsite market – namely, India. This allowed the framework to capture data and represent both developed and developing countries and associated markets. Thus, the development approach incorporated domain knowledge from across the world, representing expertise from construction, design and manufacturing. A description of these two stages are presented as follows.

5.3 Development Process: Stage 1 [Mature Markets]
Innovation in most sectors is predominantly diffused through three central ‘themes’ of People, Process, and Technology (Davenport, 1992). These core themes were considered pivotal for the development of this framework, as they embraced the three dominant paradigms drivers of offsite, along with their enmeshed relationships (Figure 5.2). In line with this approach, one of the main challenges was to investigate the People, Process, and Technology dimensions of offsite construction through an ‘operationalisation’ research lens. This approach obfuscated the challenges often associated with mono-dimensional views that engage single parameters, with limited contextual anchors. The development of the assessment framework was therefore considered an important and challenging task. Given the complexities involved in the establishment of the roadmap, it was subsequently deemed important to embed a high degree of flexibility into the roadmap, so that this could be adapted for different countries and future research. The roadmap and core interrelated areas were subsequently populated through a series of webinars and supportive workshops.

Figure 5.2 Core Interrelated Areas: Design, Construction and Manufacturing

From Figure 5.2, nine core areas are presented, representing the three major dimensions of offsite construction: Process, Technology and People, and their impact on: Design, Manufacturing and Construction. These issues were informed by literature through seminal works - the issues/priorities of which were subsequently discussed through the webinars and evaluated/prioritised through two workshop sessions. The first step was to gain high-level insight into the nine areas identified. Each of the nine areas were then cross-correlated against each of the two workshop sessions in order to secure parity and
consistency of findings. This process also helped secure data veracity, which was needed for inference testing and data validity purposes. A discussion of the findings from each of these areas follows.

**Design-Technology:** In order to manufacture a building or a component of a building, it is important to look at the manufacturing sector in general in order to consider the adoption of lessons learnt in the building process. It is also important to improve customer focus and implement Design for Variety (DFV) principles as proposed by Veenstra et al., (2006); and perhaps engage product design optimisation techniques proposed in Concurrent Engineering (Fixson, 2005). Given this, there was a need to embed technology into the design process itself in order to analyse the different options available before committing to a particular design or configuration. Moreover, the adoption of Building Information Modelling (BIM) philosophy and similar technologies for the offsite sector (Nawari, 2012) was also a key requirement. The major issues within these areas for consideration in the roadmap were:

- Enhanced design process through the application of concurrent engineering based design philosophy. Given that in an offsite construction scenario design, manufacturing and construction roles have to come together. Therefore, this was an important philosophy to implement;
- Greater BIM adoption is key to success in the future. The amount of insight into complex issues that BIM can provide at the design stage is openly recognised. It is important that organisations take advantage of this capability and facilitate such issues as concurrent engineering implementation through BIM-type platforms;
- Clearer supply chain benefits are quite important to establish at the beginning of the project. This can often lead to a higher dependency on dedicated resources by the supply chain, but can help teams visualise value-added activities.

**Manufacturing-Technology:** One of the key debates regarding manufacturing technology is the level of automation required (Frohm, 2008). For example, can you justify automation in a sector such as construction with a high product variety (Veenstra et al., 2006), and with significant variations in demand? When analysing this, there is a specific need to have flexible and reconfigurable manufacturing systems that can absorb product variability through configurations in the production line (Columbo and Harrison, 2008). Effective supply change integration is an important factor, especially through Enterprise Resource Planning (ERP) type systems in order to achieve effective and cohesive offsite supply chains (Arif et al., 2005). Integration of modelling and simulation as well as decision support systems therefore need to be implemented for effective planning and execution of the manufacturing process (Arif et al., 2002). The major issues within this area that needed to be considered for incorporation in the roadmap were:

- Simulation and modelling tools - to gain more insight into processes and implications of different decisions. Given the gaining popularity of BIM, it was considered worth investigating the integration of discrete events software into BIM outputs;
- Business cases are needed for software such as ERP, as they are quite expensive (with a long payback period). Even for mass production, it was considered difficult to produce a centralised location where large production runs can be achieved, as costs associated with transportation of these buildings from one central location would be prohibitive. In order to establish a decentralised production system, with production facilities spread over large geographical areas, new types of software and communication protocols would be needed. A different kind of business case would also be needed to justify this;
Optimisation of the manufacturing payback period is important when considering the implementation of expensive software and hardware. The initial upfront cost of establishing a manufacturing facility could be significant - it was considered important to consider the payback period before choosing the best option. More work needs to be done in this area, along with the levels of automation needed.

**Construction-Technology**: The construction process is highly dependent on the planning process, and construction planning tools are an essential component of the delivery process. As BIM is increasingly gaining acceptance as the preferred method of communicating the design intent to a range of disparate stakeholders, these data-rich models are now being used by the design team to coordinate activities. This has innumerable advantages in off-site construction, including faster delivery, better economic indicators, along with improved sustainability factors and enhanced safety measures (Nawari, 2012). The construction technology debate also acknowledged the heavy lifting intensive operations often involved with construction and assembly. New types of construction technologies were considered more conducive to assembly rather than construction *per se*. The major issues for consideration in the roadmap were:

- Identification of technology support tools - to help the overall operations involved in offsite construction;
- Better understanding of risk analysis in the context of offsite - as the execution tends to be divided between manufacturing and construction (the additional dimension of manufacturing therefore has to be accounted for, and risks associated with its interface with both design and construction needs to be considered);
- Improving product modelling flow using BIM.

**Design-Process**: It was acknowledged that design had to be more systematic, using a holistic approach that analyses the different variables in order to add value to the implementation or manufacturing part of a service or a product (Whitney, 1990). This requires a critical reflection of the value added activities e.g. through design decisions, analysis of impact on stakeholders, and through improved understanding of the overall impact of design on the manufacturing and construction processes. The design process needs to be seen as a radical holistic planning process for the efficient execution of an offsite project. The major issues within this area for consideration in the roadmap were:

- Adding value to the process - considering such approaches as Design for Manufacturing and Assembly, Concurrent Engineering etc.;
- Improving the impact of design/technology using BIM;
- Better lifecycle process analysis - incorporating an additional manufacturing interface.

**Manufacturing-Process**: This evaluated the issues for dealing with the manufacturing of construction products, especially since this requires the active involvement of the customer, much more than traditional mass production models (Stump and Fazleena, 2012). For example, with house construction, the customer tends to get involved right from the beginning. Issues of importance included the need to evaluate new and alternate business models to ensure that effective solutions can be procured. The major issues within this area for consideration in the roadmap were:
Learning from other industries - manufacturing has contributed significantly to aerospace, IT, communication and several other sectors. Offsite is a relatively new endeavour for manufacturing into construction. However, there are several similar industries that offsite construction can draw lessons from, including ship building. These processes are quite comparable, as the ship building industry uses modules similar to those used in a modular home;

New business models are needed - especially to look at the value proposition, taking into account issues such as mass customisation. Given the variation in product design, a standard mass production approach might not work - there is a need to look at mass customisation as an alternative;

Identifying the breakeven point for automation is important - the manufacturing facility can incorporate high degrees of automation and robotics. However, there is the issue of having sufficient production runs to justify the upfront costs of this infrastructure. Another alternative to automation could be mechanisation. In order to implement offsite, it is important to balance between levels of automation or mechanisation.

Construction-Process: Pan and Goodier (2012) documented some important issues concerning business models, construction processes, and the relationship of these to offsite construction. They proposed a top down and a bottom up strategy; but also asserted that additional work was needed in this area before more robust business models and operating models could be developed. This discussion helped inform debate within the workshops on the important processes involved. The major issues captured for consideration in the roadmap were as follows:

- Integration of core processes within BIM - process modelling is very important, especially through “what-if scenarios”;
- Greater flexibility is needed on the construction site to accommodate the constraints of the manufacturing process. Process flexibility is important to capture different size and different formats (volumetric, non-volumetric etc.) of offsite components;
- Improving the interface of offsite production - especially to coordinate activities with manufacturing and the scheduling of equipment and personnel (so that they are ready when the manufactured component arrives on site).

Manufacturing-People: Kagioglou et al., (2000) highlighted that the major difference between the manufacturing and construction sectors was ostensibly a product-focus issue versus project-focus issue. Given this, in order for manufacturing to deliver construction products, it is important that it embraces a more project-centric view on the product. This requires close collaboration with both the design team and on-site installation team in order to facilitate a smooth execution of the process. The major issues within this area for consideration in the roadmap were:

- Improving integrated decision modelling – people need to understand how the whole process (design, manufacturing, construction) intertwines and works together, along with the major roles needed (as this can affect decisions throughout the whole supply chain);
- Maximising training impact by educating people from all three functions (design, manufacturing, construction);
- Alignment of new job roles to reflect the interfaces such as design-manufacturing and construction-manufacturing.
Design-People: In order to effectively plan and design an offsite construction project it is important that all people involved in the design are aware of approaches such as Concurrent Engineering, Design for Manufacturing (DFM) and Design for Manufacturing and Assembly (DFMA). These approaches have several acknowledged benefits, including the reduction of production costs, and adding value by recognising design conflicts leading to rework in the manufacturing process (Li et al., 2011). The major issues within this area that need to be considered for the roadmap were:

- Importance of DFM, DFMA and logistics - a radical approach to design is needed that incorporates suppliers, assemblers and manufacturers. For example, Design for X, where X could be constructability, sustainability, maintainability etc.;
- Need for a new approach to design (which is a completely new paradigm) - this needs new skills and new thinking to change individual and company behaviour (to work with manufacturing and construction). These new skills were not critical in the past, but are now.

Construction-People: The effective execution of the construction part of the process requires people to be retrained with assembly-type skills, rather than purely construction skills. This up-skilling should embrace sustainability to deal with this new paradigm of construction (Egan, 1998). This approach should also place additional emphasis and recognition on the Health and Safety benefits of offsite construction (Nahmens and Ikuma, 2012). The major issues within this area that need to be considered for the roadmap were:

- Promoting sustainability along all three dimensions - social sustainability benefits can occur through the continuity of employment (for people working in a factory environment); economic benefits because workers within the factory could be expected to have more stable and long term employment (compared to locally-employed manual site jobs); and environmental sustainability, since transportation could be arranged for factory workers (thereby reducing vehicular traffic, emissions etc.);
- The need for up-skilling of personnel – especially on the installation of pre-fabricated products and modules on site. Significant investment in training to facilitate this up-skilling endeavour would be needed here;
- Improving Health and Safety through specialised training.

Development of Key Priorities (short-term and medium-term)

The above discussion led to the confirmation of these nine relationships [termed variables], which were categorised under the following areas:

- People Drivers [Construction:People; Manufacturing:People; Design:People];
- Process Drivers [Construction:Process; Manufacturing:Process; Design:Process];
- Technology Drivers [Construction:Technology; Manufacturing:Technology; Design:Technology]

Each of these variables were placed into one of two time-framed categories, namely: “Short-term Priorities (0-5 Years)” or “Medium-term Priorities (6-10 Years)”, depending on the confirmed level of importance agreed through the two workshop sessions. These nine core areas cover the three main drivers [people, process, and technology], the interrelationships of which can be seen in Appendix ‘A’. Each of these three
drivers were then subdivided into priority areas and placed into a timeframe category of either short-term or medium-term. Within this classification, a further series of priorities were assigned i.e. P1, P2 or P3. Where: P1 = Priority 1, P2 = Priority 2, and P3 = Priority 3. For example, from a People Driver perspective, it can be seen that the main area of focus was placed on “Design:People” [High], followed by “Construction:People” [Medium], then “Manufacturing:People” [Low]. The “Design:People” category was classed as high priority and should be addressed within the timeframe of 0-5 years. Within this, the three areas of focus were: P1 Importance of DfMA and logistics; P2 Need for new skills; and P3 Need for new approach to design. The “Construction:People” category was classed as medium priority and should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Upskilling personnel, P2 Promoting sustainability, and P3 Improving Health & Safety. The “Manufacturing:People” category was classed as low priority and should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Improving integrated decision modelling, P2 Maximising training impact, and P3 Alignment of new job roles (to new requirements).

From a Process driver perspective, it can be seen that the main area of focus was placed on “Construction:Process” [High], followed by “Design:Process” [Medium], then “Manufacturing:Process” [Low]. The “Construction:Process” category was classed as high priority and should be addressed within the timeframe of 0-5 years. Within this, the three areas of focus were: P1 Greater flexibility needed, P2 Integration of process with BIM, and P3 Improving the interface of OSP. The “Design:Process” category was classed as medium priority, but was placed within the timeframe of 0-5 years as respondents classed this as an important area to address. Within this, the three areas of focus were: P1 Adding value to the process, P2 Improving the impact of design/technology, and P3 Better lifecycle process analysis. The “Manufacturing:Process” category was classed as low priority and should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Learning from other industries, P2 New business models needed, and P3 Identifying breakeven point for automation.

From a Technology Driver perspective, it can be seen that the main area of focus was placed on “Construction:Technology” [High], followed by “Design:Technology” [Medium], then “Manufacturing:Technology” [Low]. Whilst the “Construction:Technology” category was classed as high priority, respondents determined that this should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Improving product modelling flow, P2 Identification of technology support tools, and P3 Better understanding of risk analysis. The “Design:Technology” category was classed as medium priority, which should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Greater BIM adoption, P2 Clearer supply chain benefits, P3 Enhanced design improvements. The “Manufacturing:Technology” category was classed as low priority, which should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Optimisation of manufacturing payback, P2 Business cases needed for software (selection), and P3 Simulation and modelling tools needed (to help predict outcomes).

In summary, the roadmap presented in Appendix ‘A’ presents both industry and the research community with a series of focal areas that need to be addressed over a 10-year period. Short-term priorities need to focus on untangling the Design:People interaction and relationships, particularly regarding the importance of DfMA and logistics, and the skills required to leverage benefits. Other short-term priorities include the need to focus on “Construction:Process”, regarding enhancing the flexibility of process to better align to BIM and offsite production; and “Design:Process”, where there is a need to ascribe ‘value’ to the process, especially with design and its impact on lifecycle analysis. Finally, there is a need to emphasise the importance of “Construction:Technology”, especially concerning product modelling, the use of technology support tools, and improving stakeholders’ understanding of risk and rewards.
5.4 Development Process: Stage 2 [Developing Markets]

Stage 2 of the development process engaged 75 delegates from the offsite community in India. These delegates represented approximately the same mix of expertise identified in Stage 1, with domain strengths covering a broad spectrum of expertise taken from the offsite market, including a range of suppliers and product manufacturers, through to engineers, designers, contractors etc. It was recognised that this cross section of expertise/knowledge was ideal for being able to reflect the needs of new/developing markets (vis-à-vis priorities and direction), in contrast to stage 1, which used respondents from mature markets only. Given this distinction, the findings are presented separately for discussion.

From a People driver perspective, the main focus was placed on “Design:People” [High], followed by “Manufacturing:People” [Medium], then “Construction:People” [Low]. The “Design:People” category was classed as high priority which should be addressed within the timeframe of 0-5 years. Participants realised that there was a need for an altogether different kind of design paradigm. This area was perceived to be behind that of developed countries, and more awareness needed to be created for this area to progress. Within this, the three areas of focus were: P1 Importance of DfMA and logistics; P2 Need for new approach to design; and P3 Need for new skills. The “Manufacturing:People” category was classed as medium priority and should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Improving integrated decision modelling, P2 Maximising training impact, and P3 Alignment of new job roles (to new requirements). The “Construction:People” category was classed as low priority and should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Promoting sustainability, P1 Upskilling personnel, and P3 Improving Health & Safety. There was consensus of opinion that there needed to be a significant increase in the training and educational provision in India in order for this area to prosper.

From a Process driver perspective, the main area of focus was placed on “Design:Process” [High], followed by “Manufacturing:Process” [Medium], then “Construction:Process” [Low]. The “Design:Process” category was classed as high priority, which should be addressed within the timeframe of 0-5 years as respondents classed this as an important area to address. Within this, the three areas of focus were: P1 Adding value to the process, P2 Improving the impact of design/technology, and P3 Better lifecycle process analysis. This sequence is exactly same to that presented for developed countries. The “Manufacturing:Process” category was classed as medium priority and should be addressed within the timeframe of 0-5 years. Within this, the three areas of focus were: P1 Learning from other industries, P2 New business models needed, and P3 Identifying breakeven point for automation. The sequence of priorities was also the same as that identified for the developed countries [mature markets]. The “Construction:Process” category was classed as low priority and should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Integration of process with BIM, P2 Greater flexibility needed, and P3 Improving the interface of offsite production.

From a Technology driver perspective, it can be seen that the main area of focus was placed on “Design:Technology” [High], followed by “Manufacturing:Technology” [Medium], then “Construction:Technology” [Low]. The “Design:Technology” category was classed as high priority, which should be addressed within the timeframe of 0-5 years. Within this, the three areas of focus were: P1 Enhanced design improvements, P2 Greater BIM adoption, and P3 Clearer supply chain benefits. It was noted that design technologies would have a regulatory impact, therefore the involvement of regulatory bodies would be important. The “Manufacturing:Technology” category was classed as medium priority, which should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P3 Simulation and modelling tools needed (to help predict outcomes), P2 Business cases needed for software (selection), and, P3 Optimisation of manufacturing payback. The “Construction:Process” category
was classed as high priority, respondents determined that this should be addressed within the timeframe of 6-10 years. Within this, the three areas of focus were: P1 Identification of technology support tools, P2 Better understanding of risk analysis, and P3 Improving product modelling flow.

In conclusion, the roadmap presented in Appendix ‘A’ presents the industry with a series of focal areas that need to be addressed over the short to medium term. Short-term priorities should focus on disentangling all the three dimensions of Design: people, process and technology. For the Design:People category the highest priority was the emphasis on communicating the importance of DIMA and logistics. This new way of thinking is important for realising efficient ‘manufacturable’ designs. Architects and designers should therefore be cognisant of this. The second priority was to understand other issues to keep in mind when designing for manufactured construction. The lowest priority was the development of new skills, and hence, the need for new education and training programmes in this area. Design:Process was another important short term priority. For this category, the priorities in order of importance were: adding value to the process, improving the impact of design/technology, and securing improved lifecycle process analysis. Design: Technology is the other dimension of design that was regarded as high priority in the short term. In this category, priorities in order of importance included: enhanced design improvements, greater BIM adoption, and clearer supply chain benefits. Other short-term priorities included the need to focus on “Manufacturing:Process”, regarding learning from other industries; and the identification of new business models to operate manufacturing in the construction sector. The least important emphasis in this category was to identify the breakeven point for automation. Given the availability of ‘affordable’ labour in India, this item was rated lowest among the manufacturing process priorities.

5.5 Summary
The culmination of TG74’s work is presented in the form of a prioritised offsite production and manufacturing research roadmap – see Appendix ‘A’. This encompasses both mature markets from the developed world, and new/emerging marks from the developing world. Whilst acknowledging the different contexts, positioning and priorities, it was considered important to tease out some of the main findings. For example, it can be seen that in the people dimension, the rating for design is classed as high. There is recognition in both the developed world and India that in order to succeed at implementing offsite construction, both manufacturing and assembly designers should be effectively trained in order to consider the manufacturing and assembly dimensions - hence the need for immediate action this area. In the developed world, construction was classed as medium priority; whereas, in India, manufacturing was considered medium priority. One of the predominant reasons being that significant manufacturing infrastructure already tends to exist in developed countries; and currently, higher emphasis was placed on getting the onsite assembly process right (and synchronised with manufacturing). Whereas, in India the manufacturing infrastructure still needs development before offsite can be adopted by the construction sector.

From a process dimension, the highest priority for the developed world was construction; whereas, for India the highest priority was design. This again is recognition that in the developed world implementation started before India; the emphasis was therefore on ensuring overall cohesion of the process leading to efficient onsite operations for assembly. In India a different paradigm of design is therefore needed which starts at the very beginning, i.e. designing offsite implementation into the product itself. For developed markets the second important priority was design and the use of new ways of designing, using new philosophies and techniques such as BIM. However, in India, the concept of manufacturing for construction was new; therefore, new processes would have to be developed/adapted/adopted for the construction sector to work within the Indian context. In this regard, India has a lot to learn from the developed world in order to adopt and adapt some manufacturing processes. However, since labour is significantly cheaper in India than in
most developed countries, it is anticipated that automation would be difficult to justify for the time being. From an mature market perspective, the lowest priority of focus was manufacturing; whereas in India it was considered to be construction. The reason behind this could be that significant infrastructure exists in the developed world; whereas, in India the construction dimension is ostensibly driven by how design is carried out, and what kind of manufacturing takes place - hence construction was considered low priority.

The technology dimension highlighted similar issues. For example, in developed markets, emphasis was placed on technology – ensuring surety of product, including modelling approaches, support tools, risk etc. When considering design, manufacturing and construction as sequential sets of process; the developed world has already achieved a higher level of expertise in design and manufacturing processes, primarily because offsite has been in existence for longer. Whereas, India is still relatively in its infancy in this regards; and hence, emphasis was placed on design technology. Similarly, in the developed markets, emphasis was placed on securing greater BIM adoption (along with the support infrastructure needed to underpin this). Whilst this is still unfolding, it was considered a medium level priority. Whereas, in India a new manufacturing infrastructure would need to be developed, and was therefore considered to be medium priority. Finally, in mature markets, manufacturing was considered to be low priority for the same reason as Manufacturing:Process; whereas, in India, construction was rated low priority (for the same reason as the process dimension).
6.0 Conclusion

6.1 Introduction
This document presented an overview of the global offsite manufacturing construction sector in line with the CIB mandate and terms of reference. It highlighted the underlying market conditions, core development areas, along with the main challenges and perceptions associated with the uptake of offsite in various market sectors. For example, in developed markets, the uptake and adoption of offsite ranged between 6% and 20%. However, anecdotal evidence suggests that this could be much higher in some segmented markets depending on the precise terminologies used. Notwithstanding this, the levels of uptake are still relatively low. This is likely to change in the future, as statistical trends show positive trajectories and increased use (which is quite promising). Countries like Malaysia have been particularly proactive in this area by establishing formal centres of excellence in IBS. These are underpinned by a well-established and cohesive supply chain, rigorous regulatory control measures, comprehensive training programmes, innovative offsite product catalogues and bespoke design guides. This sets an example for the rest of the world to follow.

This document then highlighted what needed to be undertaken in the areas of skills, technology, manufacturing and innovation (in order to facilitate the future adoption of offsite construction). The main areas highlighted included the need for key skills in the areas of DfMA, production and process efficiency, planning and project integration. On this, it was noted that there was a need for smart technologies such as collaborative work environments, specialist assembly approaches, and proven modularisation techniques in product design. These are considered fundamental levers for innovation to occur. For example, in manufacturing a key missing link in the chain is the deployment of such approaches as Concurrent Engineering and other process planning tools such as Lean, Simulation and Quality Function Deployment. These are well established, and have been proven to significantly help improve process efficiency. The manufacturing element of offsite construction also needs to consider the level of automation deployed. Specifically, appropriate consideration also needs to be given to justify the level of automation used (given that mass production might not always be possible, and the recovery cost of a fully automated system might not always be viable). Finally, Integrated Product Delivery (IPD) and BIM tools have been increasingly gaining popularity over the last decade. In all cases, this is seen as a major adoption area, and one which could leverage several innovation opportunities.

With this background and current overview of the industry as a whole, TG74 set out to establish a formal list of needs, priority areas, and future direction of travel – the culmination of which is presented in a prioritised offsite production and manufacturing research roadmap (Appendix ‘A’).

6.2 Needs and Priority Areas
One of the immediate high priority areas for offsite construction included the need to focus on Design:People. This is an issue that has been highlighted as a major barrier in several dominant markets, including the USA. This really stems from a general lack of understanding from a design team perspective. Similar issues have been documented in Australia and in the UK over the past few years. Similarly, there is an overt skills gap evident across all sectors (design, manufacturing and construction). This embraces the lack of integration, and the lack of knowledge concerning each sector’s needs – from design, through to process, logistics, and operationalisation. This is a global issue, and one which embraces the majority of markets assessed. Other issues of concern centre on Construction:Process, which embraces the need to secure greater flexibility. The creation of a flexible workforce that is directly linked to process opens up new opportunities. This can also help openly demonstrate additional ‘value’ to supply chain partners, clients etc.
On this theme, the use of BIM for process integration is seen as a pivotal lever for change. These recurring issues have been acknowledged for many years now; for example, the “Construction 2020” report for the Australian property and construction industry (Hampson and Brandon, 2004) acknowledged the need to fully embrace virtual prototyping for design manufacture and operation. Whilst these recurrent issues still remain to some extent, there are several new opportunities to exploit through BIM, and especially through the integration of BIM and DfMA. The link between ERP and BIM is another potential area for innovation. Again, this highlights the need to embrace training in these new technologies. One final priority concerns the need to fully understand and embrace lifecycle analysis as part of the design-manufacture-construct continuum. Whilst such initiatives as LEED, BREEAM, CEEQUAL etc. have started to place significant emphasis on this; the offsite community can openly demonstrate significant product advantages here. For example, in the UK the ability for offsite to deliver zero-carbon homes has been recognised - which is not only important to acknowledge, but has also helped to promote, and “sell” the product to clients and the wider offsite community.

Finally, as manufacturing and automation is relatively mature in developed markets; there seems to be somewhat of a hiatus in wanting to take this forward. This was not seen to be high on the agenda compared with other areas. However, there is a need to enmesh process modelling with the manufacturing cycle. Moreover, there is a need to develop more manufacturing facilities – not only to be able to deliver the quantity of products required, but also to stimulate competition and growth (particularly in mature markets).

6.3 Future Research Agenda for Offsite

The offsite market embraces a number of complex systems. It is inextricably linked to the design, construction and manufacturing sectors. Moreover, it is also influenced by a series of forces and dynamic drivers which directly affects its future landscape (Figure 6.1). These forces and drivers are significant and palpable. Whilst research findings presented in Appendix ‘A’ identify a series of priorities mapped against two discreet timeframes, this roadmap does not overtly identify the causal stimulants and impediments to success. It is there important to endeavour to try and ‘predict’ some of these as part of the transition through these two time periods. For example, from Figure 6.1, the top left hand corner highlights “challenges”; and one of the biggest challenges is the complex nature of the offsite construction sector (and number of scenarios that can be generated). This is where the interface between design, manufacturing and construction (and the ensuing decision-making process) becomes critical. This is not insurmountable. New ICT tools such as BIM and advanced stochastic simulation models now offer unique insight into probability generation for predicting outcomes (e.g. multiple what-if scenarios). For example, undertaking a complete process review analysis using discrete event simulation packages can now provide additional high-level visibility into each different scenario generated. Other approaches using DfMA principles can also be integrated into the overall product design process, and be connected to BIM, ERP etc. This not only helps confirm surety of product, but can also be used to demonstrate innovation, value, and a raft of other metrics, including environmental, lifecycle analysis etc. However, these approaches require training. The design people would need to be trained in the complexities of manufacturing and the assembly process (which is quite different to ‘traditional’ construction); and people will also need to be trained in the use of Concurrent Engineering approaches to design (which is important to accommodate end user requirements as well as manufacturing and construction constraints into the final design). Similarly, manufacturing personnel will need to understand the complexities in the site assembly process, including logistics, transportation, handling etc. Manufacturing also needs to embrace the issue of automation, as a more automated facility might be able to produce at a higher rate, but the counter to this is that this approach might not be able to accommodate wide design variability. Manufacturing therefore needs to start to look at mass customisation rather than mass production (to address the issue of design variability). This may also have to consider the
recovery costs of investments in automation concerning production runs. Perhaps one solution might be to adopt a hybrid approach, where a semi-automated or mechanised facility is used (rather than automated) in order to adjust to the varying demand levels against design variability? Construction personnel also need to think differently (to embrace construction as an assembly paradigm) - one that engages different modalities involved with connecting modules and sub-components. However, these new methods and skills need to be embedded within each of the three elements and corresponding processes.

Figure 6.1 Future Research Agenda for Offsite

The growing emphasis on sustainability is an opportunity for offsite construction to present itself in a very positive new light. Offsite has the ability to deliver a tighter building envelope, using materials such as Structurally Insulated Panels, along with smart materials and components. It can also openly demonstrate reductions in transportation, waste and use of embodied energy in the construction process. Offsite is therefore in a strong position to present and defend viable cost effective solutions. These can also espouse other benefits, including safer working environments, improved in-use and lifecycle costs. These benefits
need to be more overt and more readily available. Customers make informed decisions based on several factors, not least the availability and veracity of material available from a range of sources. It is important to overtly promote this through such initiatives as: case studies, the implementation of extended warranty schemes; availability of ‘open’ literature supported by recognised bodies etc. This will help develop improved satisfaction levels, and in turn help strengthen demand.

6.4 Summary
The concept of offsite is not new - it dates back to the 1800s. Despite this extended heritage, the levels of offsite adoption only represents a small percentage of the potential market available. This requires a fundamental sea change in thinking. A paradigm shift is needed in how the offsite community (design, manufacturing and construction) can openly promote and defend offsite. However, this requires several issues to be addressed, not least the development of an integrated and seamless “team” which coherently aligns itself to the end product. New business models are therefore needed; as are the way in which professionals within the team interact with each other. This involves the process of change, and change management; and change is so important here. This includes new relationships, skills, technology, processes and new ways of working. There are several innovation opportunities to be secured, not least through leveraging technological solutions to proven approaches. New innovative business models are therefore advocated; ones which demonstrate the “value proposition” and firmly embed these in rigorous quality assurance systems. The future is bright and the market is readily available.
7.0 References

ACT-UK (2013), ACT-UK Simulation Centre, Coventry, UK


Alarcon, L., (1997), Lean Construction, AA Balkema, Rotterdam, Netherlands

Alshawi, M., (2007), Rethinking IT in Construction and Engineering: Organisational Readiness, Taylor and Francis, UK


Blismas, N., (2007), Off-site manufacture in Australia: Current state and future directions, Cooperative Research Centre for Construction Innovation, QUT, Brisbane, Australia

Blismas, N., and Wakefield, R., (2009), Drivers, constraints and the future of offsite manufacture in Australia, Construction Innovation, Vol. 9, Iss. 1, pp. 72-83


Davenport, T.H., (1992), Process Innovation: Reengineering Work Through Information Technology, Ernst & Young, USA


Frohm, J., Levels of Automation in Production Systems, PhD Thesis, Department of Product and Production Development Production Systems, Chalmers University of Technology, Gothenburg, Sweden


Gann, D.M., (1996), Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan, Construction Management and Economics, 14, Iss. 5, pp. 437-450


HAC (2011), Preserving Affordable Manufactured Home Communities in Rural America: A Case Study, Housing Assistance Council, Washington, USA


Hardiman, T., (2012), Changing the Way the World Builds - Greener, Faster, Smarter: Permanent Modular Construction Annual Report 2012, Modular Building Institute, Charlottesville, Virginia, USA


HM Government, (2012), Industrial strategy: government and industry in partnership, Building Information Modelling, URN 12/13

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IBS Digest (2012), Construction Industry Development Board Malaysia, IBS Centre, CIDB Malaysia, Kuala Lumpur, Malaysia


Modular.org (2013). Modular Building Institute, Charlottesville, Virginia, USA


NHBC (2006), A guide to modern methods of construction, NHBC Foundation, Amersham, UK


Prefabication and Modular Construction China. (2013), Optimising project quality, shortening project timeline and managing project risks via specialized modular construction, prefabrication and risk mitigation techniques, Expo, Shanghai, China


RICS (2010), RICS Research Making affordable housing work in India, Royal Institute of Chartered Surveyors, London, UK


http://www.irbnet.de/daten/iconda/CIB15621.pdf [accessed April, 2013]


Smith, R., and Narayananamurthy, S., (2008), Prefabrication in Developing Countries: a case study of India Without a Hitch: New Directions in Prefabricated Architecture, pp. 48-53, Proceedings of the 2008 ACSA Northeast Fall Conference, University of Massachusetts, Amherst, USA


Appendix ‘A’ Prioritised Offsite Production and Manufacturing Research Roadmap

People Drivers

Short-term Priorities (0-5 Years)
- Up skilling personnel (P1)
- Promoting sustainability (P2)
- Improving Health & Safety (P3)

Medium-term Priorities (6-10 Years)
- Importance of DfMA and logistics (P1)
- Need for new skills (P2)
- Need for new approach to design (P3)

Mature Markets

Short-term Priorities (0-5 Years)
- Adding value to the process (P1)
- Improving the impact of design/technology (P2)
- Better lifecycle process analysis (P3)

Medium-term Priorities (6-10 Years)
- Learning from other industries (P1)
- New business models needed (P2)
- Identifying breakeven point for automation (P3)

Developing Markets

Short-term Priorities (0-5 Years)
- Improving integrated decision modelling (P1)
- Maximising training impact (P2)
- Alignment of new job roles (P3)

Medium-term Priorities (6-10 Years)
- Greater flexibility needed (P1)
- Integration of process with BIM (P2)
- Improving the interface of OSP (P3)

Technology Drivers

Mature Markets

Short-term Priorities (0-5 Years)
- Greater BIM adoption (P1)
- Clearer supply chain benefits (P2)
- Enhanced design improvements (P3)

Medium-term Priorities (6-10 Years)
- Identification of technology support tools (P1)
- Better understanding of risk analysis (P2)
- Improving product modelling flow (P3)

Developing Markets

Short-term Priorities (0-5 Years)
- Identifying technology support tools (P1)
- Business cases needed for software (P2)
- Optimisation of manufacturing payback (P3)

Medium-term Priorities (6-10 Years)
- Better understanding of risk analysis (P1)
- Simulation and modelling tools needed (P2)
- Identification of technology support tools (P3)
Appendix ‘B’ Acknowledgements & Research Contributors

TG74 would like to formally thank the following contributors, workshop participants, Task Group members, and domain experts for their help and support in compiling this report.

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