OFFSITE PRODUCTION AND MANUFACTURING RESEARCH ROADMAP

SUMMARY

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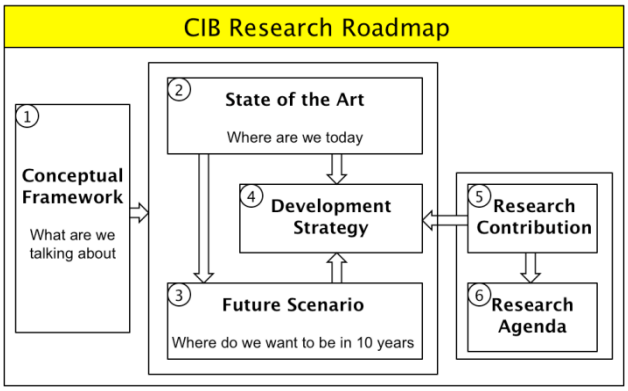

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ISBN: 978-90-6363-077-5 **CIB PUBLICATION: 375**

OFFSITE PRODUCTION AND MANUFACTURING RESEARCH ROADMAP SUMMARY REPORT

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.

FOREWORD

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

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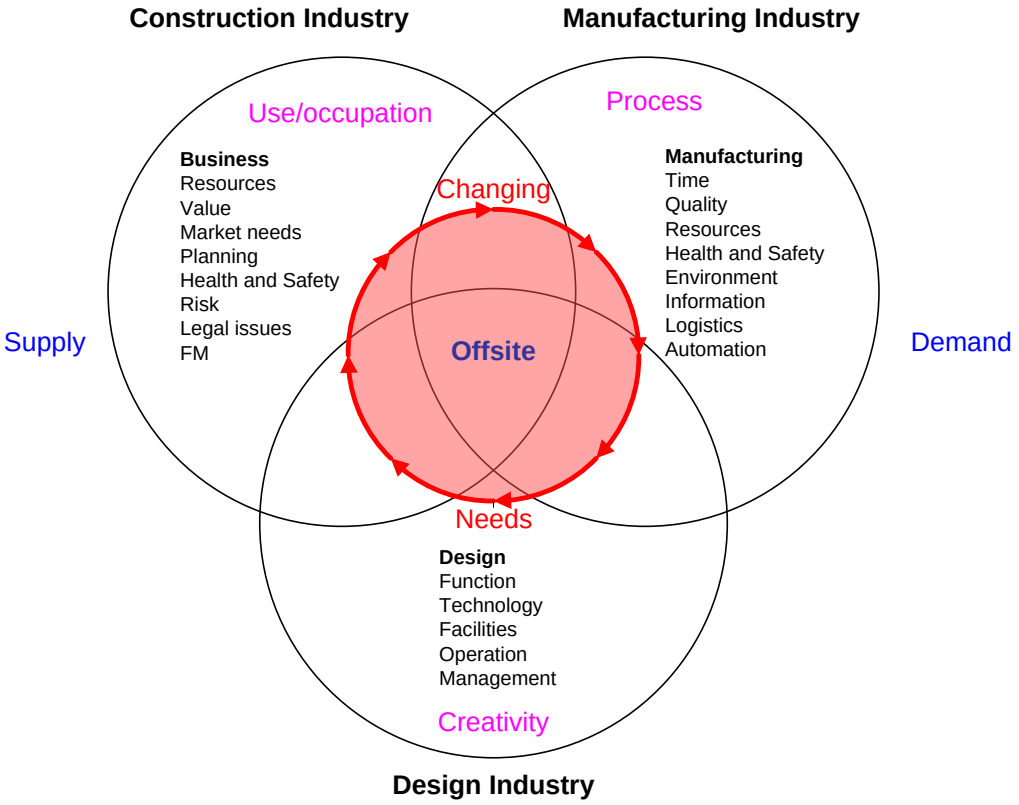
CONCEPTUAL FRAMEWORK

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 (see the figure below). 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.



Design, Construction and Manufacturing: Offsite Interrelationships

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 Building Information Modelling (BIM). However, in India, the concept of manufacturing for construction was considered; 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 a 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 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).

STATE OF THE ART

Manufactured construction, off-site construction, off-site manufacturing, industrialised building systems and modern methods of construction are all terms that that have been used interchangeably to describe pre-fabricated 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. A more detailed overview of the current offsite manufacturing developments and initiatives being undertaken in various parts of the world can be found in the full Research Roadmap.

This overview presents 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.

FUTURE SCENARIO

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. It is anticipated that the creation of a flexible workforce that is directly linked to process will open up new opportunities. This can also help demonstrate additional 'value' to supply chain partners, clients etc.

> 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)

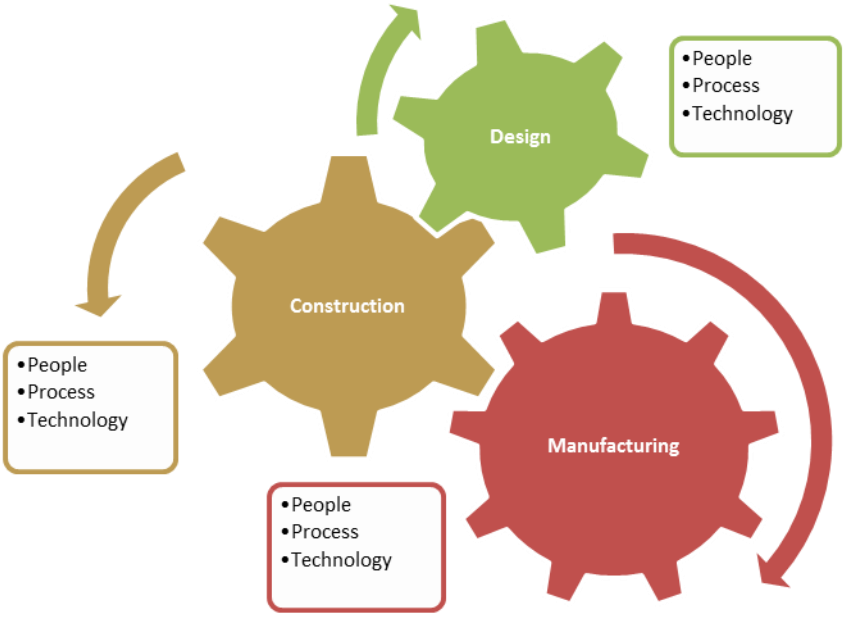
On this theme, the use of BIM for process integration is seen as a pivotal lever for change. These recurring issues have been acknowledged for many years now; for example, the "Construction 2020" report for the Australian property and construction industry (Hampson and Brandon, 2004) highlighted the 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 Design for Manufacture and Assembly (DfMA). The link between Enterprise Resource Planning (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 and also 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).

DEVELOPMENT STRATEGY

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 brief description of these two stages is presented here:

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. 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.



Core Interrelated Areas: Design, Construction and Manufacturing

From the above figure, 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 appears in the full Research Roadmap.

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 (a more detailed analysis appears in the full Research Roadmap).

> It is clear that OSM could be seen as one of the early adopters of integrated project delivery (IPD) and indeed BIM.
>
> (Davis Langdon, 2011)

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.

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, but was placed within the timeframe of 0-5 years as respondents classed this as an important area to address.

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.

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 DfMA 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 third 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.

RESEARCH CONTRIBUTION AND AGENDA

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 (see the figure below). 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 therefore important to endeavour to try and 'predict' some of these as part of the transition through these two time periods. For example, from the figure below, 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.

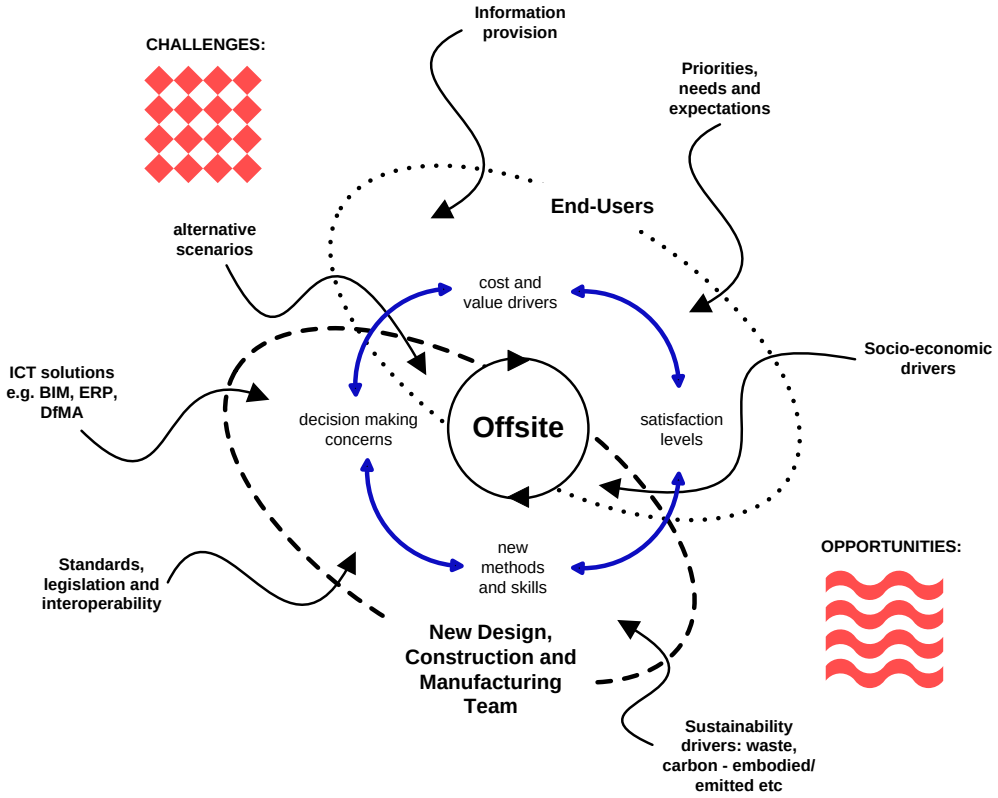
Offsite construction requires new skills in:

- Design for manufacture and assembly
- Production engineering and process efficiency
- Purchasing, planning, and materials handling
- Project integration and multi-skills

(CIC, 2013)

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

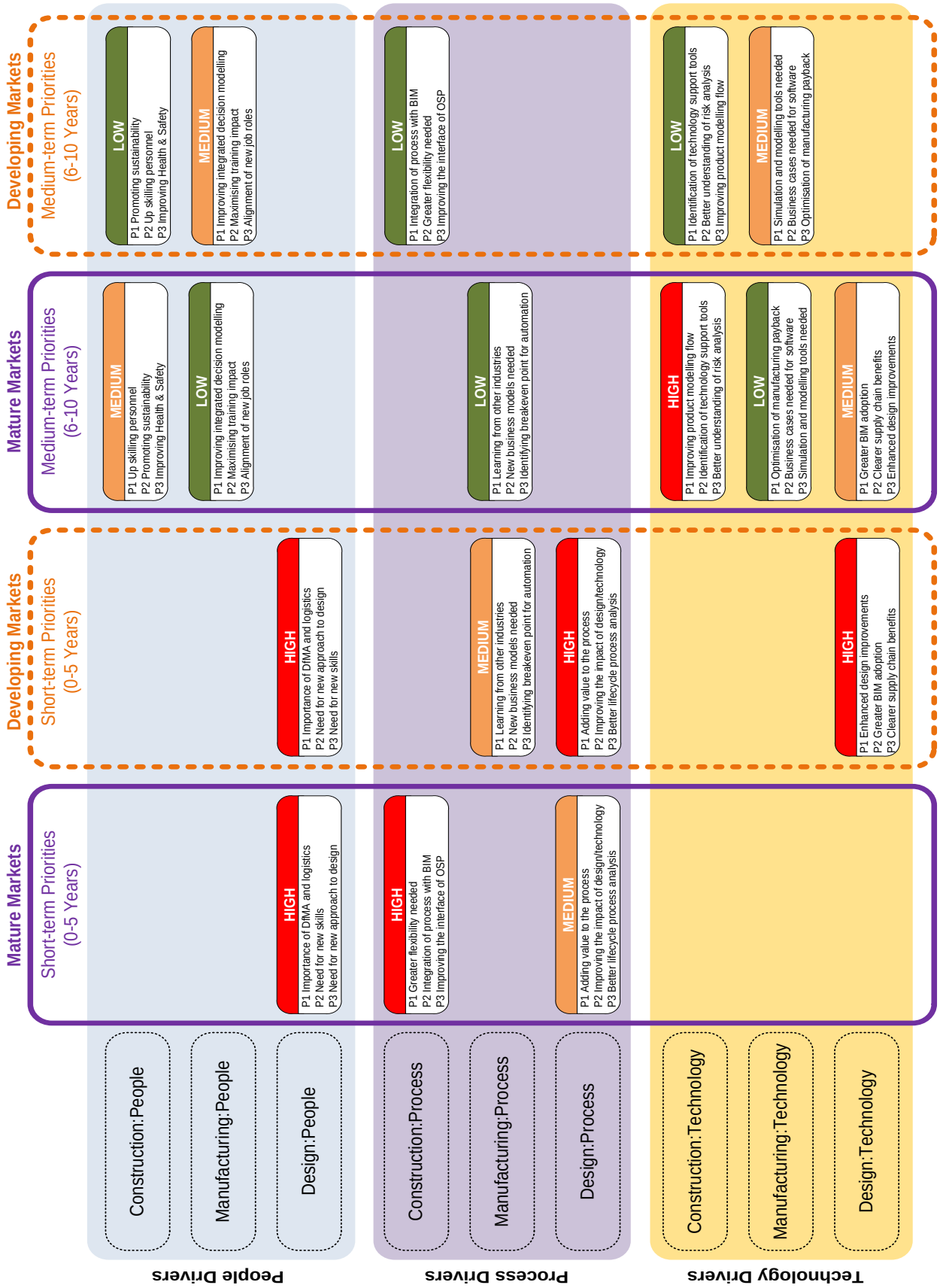
solution might be to adopt a hybrid approach, where a semi-automated or mechanised facility is used (rather than automated) in order to adjust to the varying demand levels against design variability? Construction personnel also need to think differently (to embrace construction as an assembly paradigm) - 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.



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.

APPENDIX A


People Drivers
Process Drivers
Technology Drivers
Construction:People
Manufacturing:People
Design:People
Construction:Process
Manufacturing:Process
Design:Process
Construction:Technology
Manufacturing:Technology
Design:Technology
Mature Markets
Short-term Priorities
(0-5 Years)
HIGH
P1 Importance of DfMA and logistics
P2 Need for new skills
P3 Need for new approach to design
HIGH
P1 Greater flexibility needed
P2 Integration of process with BIM
P3 Improving the interface of OSP
MEDIUM
P1 Adding value to the process
P2 Improving the impact of design/technology
P3 Better lifecycle process analysis
Developing Markets
Short-term Priorities
(0-5 Years)
HIGH
P1 Importance of DfMA and logistics
P2 Need for new approach to design
P3 Need for new skills
MEDIUM
P1 Learning from other industries
P2 New business models needed
P3 Identifying breakeven point for automation
HIGH
P1 Adding value to the process
P2 Improving the impact of design/technology
P3 Better lifecycle process analysis
HIGH
P1 Enhanced design improvements
P2 Greater BIM adoption
P3 Clearer supply chain benefits
Mature Markets
Medium-term Priorities
(6-10 Years)
MEDIUM
P1 Up skilling personnel
P2 Promoting sustainability
P3 Improving Health & Safety
LOW
P1 Improving integrated decision modelling
P2 Maximising training impact
P3 Alignment of new job roles
LOW
P1 Learning from other industries
P2 New business models needed
P3 Identifying breakeven point for automation
HIGH
P1 Improving product modelling flow
P2 Identification of technology support tools
P3 Better understanding of risk analysis
LOW
P1 Optimisation of manufacturing payback
P2 Business cases needed for software
P3 Simulation and modelling tools needed
MEDIUM
P1 Greater BIM adoption
P2 Clearer supply chain benefits
P3 Enhanced design improvements
Developing Markets
Medium-term Priorities
(6-10 Years)
LOW
P1 Promoting sustainability
P2 Up skilling personnel
P3 Improving Health & Safety
MEDIUM
P1 Improving integrated decision modelling
P2 Maximising training impact
P3 Alignment of new job roles
LOW
P1 Integration of process with BIM
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P3 Improving the interface of OSP
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