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Decision Support Tool for Enhancing the Economic Impact of Construction using Offsite Systems

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ABSTRACT

The construction industry is facing productivity stagnation across the globe, and several hypotheses to explain this phenomenon exist, most often associated with low use of digitisation, skills shortages and unpredictable market trends. Yet the economic context is more multi-faceted and the different economic drivers are closely interconnected, however research typically addresses each in isolation. This research paper aims to decipher the influence of key economic drivers on the economy, using the UK context as a barometer for international trends, and proposes how offsite technologies with varying levels of value added in the factory may be utilised to mitigate economic challenges. To achieve this, two key objectives were set: firstly to propose a theoretical framework supported by previous research on decision-support for offsite systems; and secondly to develop an infographic style visualisation to express this theoretical framework as an interactive tool. Following from the dual nature of the research objectives, the research employs a mixed methodology rooted in qualitative research techniques dealing with complex subject matters. A robust literature review with associated subsequent framework proposal was the first stage of the research, followed by data visualisation experiments and tools usability trials using focus group methods to collect preliminary data. The results indicated that there was existing evidence upon which to base the theoretical framework for enhancing economic impact using offsite solutions, with six key strands: sustainability, culture, human capital, productivity, digitisation and regulatory. However, the visualisation of this framework into an interactive tool was a novel concept and required an inter-disciplinary approach for data representation. Overall, this paper presents a unique qualitative tool, which can be utilised to simplify the concepts behind offsite construction and the potential economic impact of using offsite. The tool is aimed at decision-makers and stakeholders who may not be familiar with modern methods of construction, and those who would like to prioritise offsite benefits in a given scenario.

KEYWORDS

Offsite construction; Sustainability; Productivity; Decision support; Economic tools; Data visualisation

INTRODUCTION

Off-site manufacturing (OSM), where a part of the construction process is transferred to a controlled factory environment, is becoming increasingly important for the efficient use of resources globally in a time of unprecedented need to reduce the environmental impact of the built environment (Guglielmo and Nitesh 2017). OSM is based on the principles of efficiency and quality employing manufacturing techniques in a factory applying a lean philosophy which is conducive to an environment for innovation. Consequently, offsite is often considered to be a "Modern Method of Construction" (A UK Government term used to primarily describe innovations in house building) (NAO 2005). MMC are about better products and processes. They aim to improve business efficiency, quality, customer satisfaction, environmental performance, sustainability and the predictability of delivery timescales. OSM as a type of MMC can, therefore, be utilized to respond to the economic challenges and aspirations of the construction industry.

Economic drivers and the reaction of OSM

One of the key leading drivers for OSM is the trend of decreasing the environmental impact of the built environment, through improved air-tightness and insulation (Miles and Whitehouse 2013). In addition overall social, economic and environmental sustainability can be improved by application of circular economy principles (Hairstans and Duncheva 2019; Webster 2017). Yet Sustainability is only one driver and other factors such as the 'productivity puzzle', new and increasingly stringent regulations and increased opportunities for digitisation are all steering towards increased use of OSM. Pivotal is also human capital, the inborn skills and acquired skills, which if adequately invested in, can serve as the foundation upon which to build improved wide-ranging cultural relationships in the construction industry. (Jerzak 2015; Pye Tait Consulting 2017). The granulation of each of these main drivers and the proposed reaction of OSM are shown in Table 1. The OSM reactions are based on previous studies, which have outlined the opportunities and challenges of OSM (Miles and Whitehouse 2013; NHBC 2016; Pan et al. 2012).

Table 1. Economic drivers for OSM and OSM's reaction as factors for decision-making

Driver	Factor	OSM reaction
Sustainability	Impact: social, environmental, economic	Reduced time on site and logistics optimisation
	Circular economy	Whole life-cycle approach
	Design for Manufacture and Assembly + Disassembly	Component-based mass customisation
Regulatory	International protocols	Increased export opportunities
	EU & UK frameworks and policies	Third party accreditation
	Industry standards and quality assurance	Quality management system
Digitisation	Internet of things	Integrated multi-disciplinary design
	Fourth industrial revolution	Automated production lines
	Building Information Management	Design and production components with attached information
Productivity	Lean theory and automation	Labour and materials resources optimisation
	Construction industry performance	Inherent efficiency theory

Driver	Factor	OSM reaction
	Economic impact	Increased housing delivery capacity
Table 1 (contd.)		
Driver	**Factor**	**OSM reaction**
Human Capital	Collaboration	Local multi-skilled labour force
	Leadership	Talent attraction and retention
	Skills gaps	Reduced need for labour onsite
Cultural	Business models	Supply chain integration
	Health & Safety	Reduced manual handling and work at height
	Contractual basis	Collaborative contracts with reduced adversity
References utilized to devise the table		
(Hairstans and Duncheva 2019)		(Miles and Whitehouse 2013; NHBC 2016; Pan et al. 2012)

Infographic visualisation

The effective communication of complex information has been the subject of study and experimentation for centuries, and could be said to originate from the 1786 *The Commercial and Political Atlas* by the Scot William Playfair (Playfair 2010). Recent research has demonstrated that infographics as a method of communication is especially relevant in today's age when people are overwhelmed with 'unprocessed heap of data an information traffic' (Dur 2014). The high impact potential of information architecture has recently been utilised by UK public bodies to communicate pressing matters in construction, such as the size and workforce of the construction industry, as well as to attract new talent amidst a skills shortage (Go Construct 2018; HM Government 2015).

Justification for this research

Overall, many economic factors can drive the offsite construction sector, and vice versa offsite methods can be utilised to drive change in the construction process in reaction to economic factors. But no previous study has attempted to visualise the interaction between economic factors and OSM using the newly developed field of infographic communication.

The aim of this research is therefore to create a qualitative tool which considers each of the drivers with relevance to both the given economic context and OSM's reaction, in order to improve the decision making process. It will help to hone the thought process of selection within decision makers who may have limited knowledge of OSM or indeed construction approaches. It aids the conversation and simplifies the concept of the varying drivers involved.

METHODOLOGY

To create this tool a series of workshops were held, based upon qualitative methods (Atkinson and Delamont 2011). In attendance were the researchers and graphic designer, and the workshop average duration was 2 hours across 5 workshops.

Firstly, the aim of the tool was defined – to assist decision makers in understanding the characteristics of OSM according to key drivers they may prioritise. The drivers were identified based on previous work by the authors captured in a book chapter (Hairstans and Duncheva 2019).

Secondly, a few drafts were developed with options for the visualisation of the tool, with two main concepts. One of them was a mechanism-type with a set of cogs being turned with a number label set according to the priority of each driver. This was three-dimensional and required complex user input at the beginning to set priority of each driver, and of each factor, with ideally a suggested OSM system displayed as output at the end of the process. The other concept was that of the colour wheel, in which categories can be paired with the use of two layers, the top of which has perforations to reveal, in the case of colours, complementary, analogous or triadic colours. An applicability analysis stage followed, where the pros and cons of each proposal were reviewed by the researchers using tools from business knowledge development for decision-makers (Arbnor and Bjerke 2009). The colour wheel option was identified as more intuitive to understand and brought forward for development.

The results shown in the following sections outline this development process, whose nature was qualitative. In further publications results will also be presented from two validation sessions held in the UK and the USA with experts from the offsite construction industry. Their backgrounds were diverse including quantity surveyors, architects, engineers, executives, directors, planners and others. The written questionnaire feedback received remains to be analysed, however verbally the focus group participants confirmed the usability of the tool and made some minor comments about the future refinement of the included factors. It is anticipated that combinatorial matrix theory may be utilised to refine the tool, due to its applicability in qualitative analysis (Anderson et al. 2007).

RESULTS

The visualisation process started with the creation of a framework to explain the effects of the six main economic drivers and their three key factors per driver. This is shown in Fig. 1, where the drivers are represented as part of a circle, with each driver segment offset against the centre-point. This created the instant visual impression of a whole formed by the drivers, yet maintaining the distinct character of each driver through the use of analogous colours in the blue-green range. The impact of external influencers was mapped using concentric circles and placed where their impact was strongest. To take for example the effect of macro-factors on culture and human capital, this is further influenced by political decisions, changes in demographics as well as the levels of investment in the construction industry. The final element of this initial infographic representation was the ‘web’ of inter-connectedness between each economic factor, which reinforced the concept that each element cannot be viewed in isolation. A simple single-tone design was selected for this, in the form of a curved line (in keeping with the circular theme), whose one end was set to a white colour, transitioning gradually to a dark grey. The change in colour indicates the direction of influence, with the darker colour indicating the influencer.

Although this was a useful first step in the qualitative visualisation of the economic drivers, it omitted the reaction of OSM to each driver. To mitigate this, a further iteration was developed, which built upon the initial idea but also included an additional concentric circle with OSM factors, as shown in Fig. 2. A complementary colour range of yellow and red was selected, to highlight the difference between the economic and OSM factors. The OSM reaction was moreover visualised as a dial, which could potentially be rotated to identify priorities for an OSM project. With such a mechanism it could be possible to identify the most applicable type and level of enhancement of OSM systems, as shown in the extremities of the infographic and highlighted with dashed lines.

However, on revision of this approach it became apparent that the complexity of the infographic had increased drastically and it no longer communicated effortlessly the connection between economic drivers and OSM. The image included complex instructions and the eye of the viewers was distracted by amount of information without having the option to turn the dial.

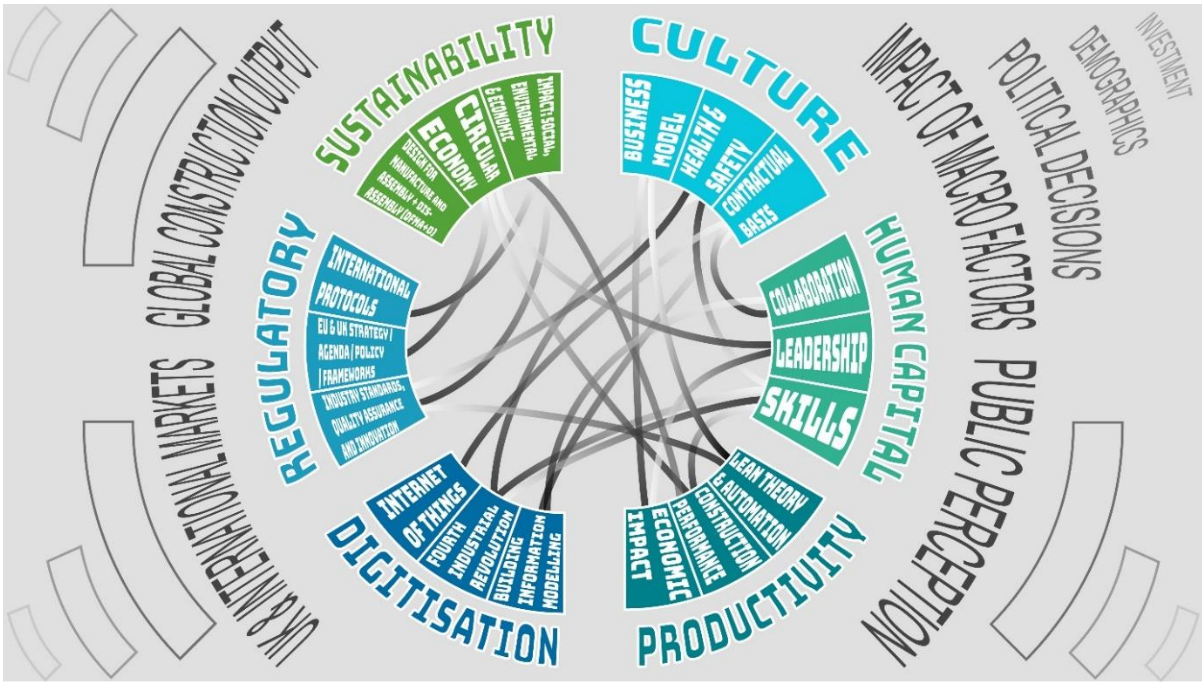

Figure 1. Infographic representation of the six key economic drivers and their inter-connectedness.

Figure 2. Infographic representation of the six key economic drivers and the OSM reaction as a decision-making tool (Hairstans and Duncheva 2019).

Colour wheel

The idea was therefore advanced with further iterations at two workshops, during which two options were presented for the simplification of the infographic. The first was a SketchUp model resembling a motor with a series of concentric circles, each of which corresponded to and economic or offsite factor. However, the usability of this model was insufficient, as it retained the complexity of the previous iteration. The second option was the colour-wheel model, where two layers are used to form a simple tool with rotating functionality. Openings in the above layer enable identification of complementary or analogous colours. This same approach was applied to the OSM tool and the resulting infographic is shown in Figs. 3 and 4. Only the blue-green range of colours was maintained, to reduce confusion to the reader's eye. Different opacity was utilised to differentiate between the economic drivers (darker, inner circles) and the OSM reaction factors (lighter, outer circles). The order of each factor in relevance to the centre indicated the connectedness between the economic and OSM factors. For example the first sustainability factor (circular economy) corresponded to the first OSM factor (whole life-cycle approach). To enable reading of the tool, a second grey layer with some opacity and six openings was created. When the two layers were combined, the second grey layer could be rotated to identify the connection between economic drivers and OSM. This tool could be used by decision-makers to simplify the concept of OSM and to steer towards OSM strengths which would be most applicable to a given scenario. Let's take the hypothetical example of a stakeholder who is keen to tackle the skills gap experienced by their business and increase the productivity performance of their projects. Through the use of the colour wheel they would be able to instantly identify the reduced need for onsite labour with OSM as well as the inherent efficiency theory of OSM as the two main factors, upon which they can focus.

a) **b)**

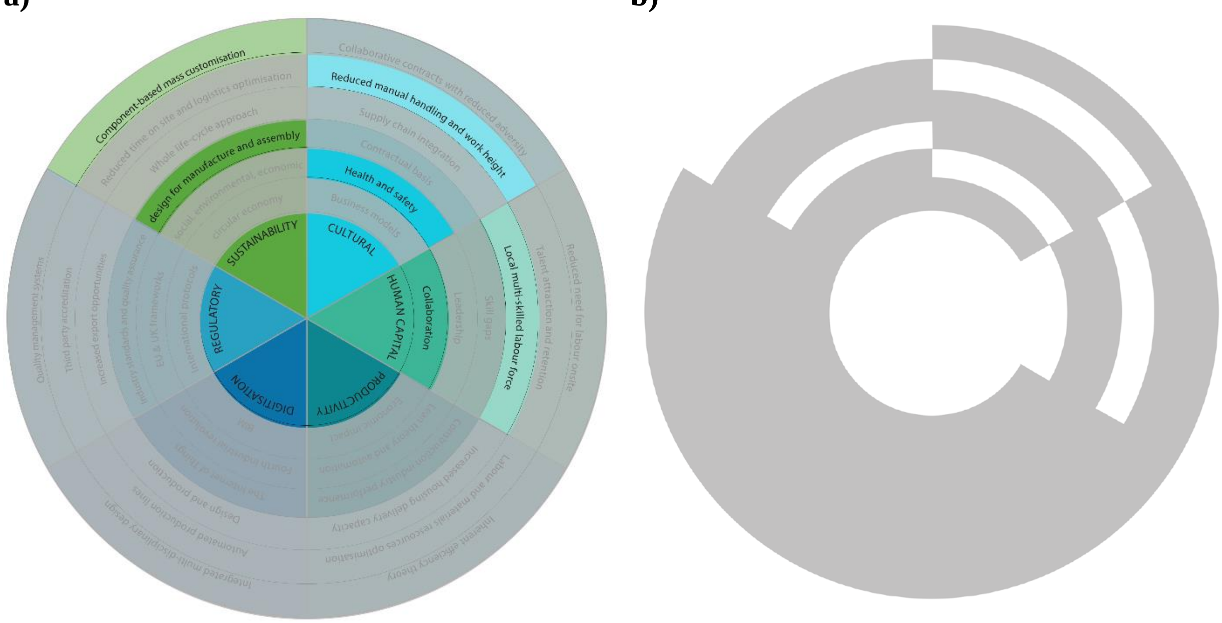

Figure 3. OSM decision-making tool: a) both layers combined. b) 2nd layer with perforations designed to pair driver factors with OSM reactions.

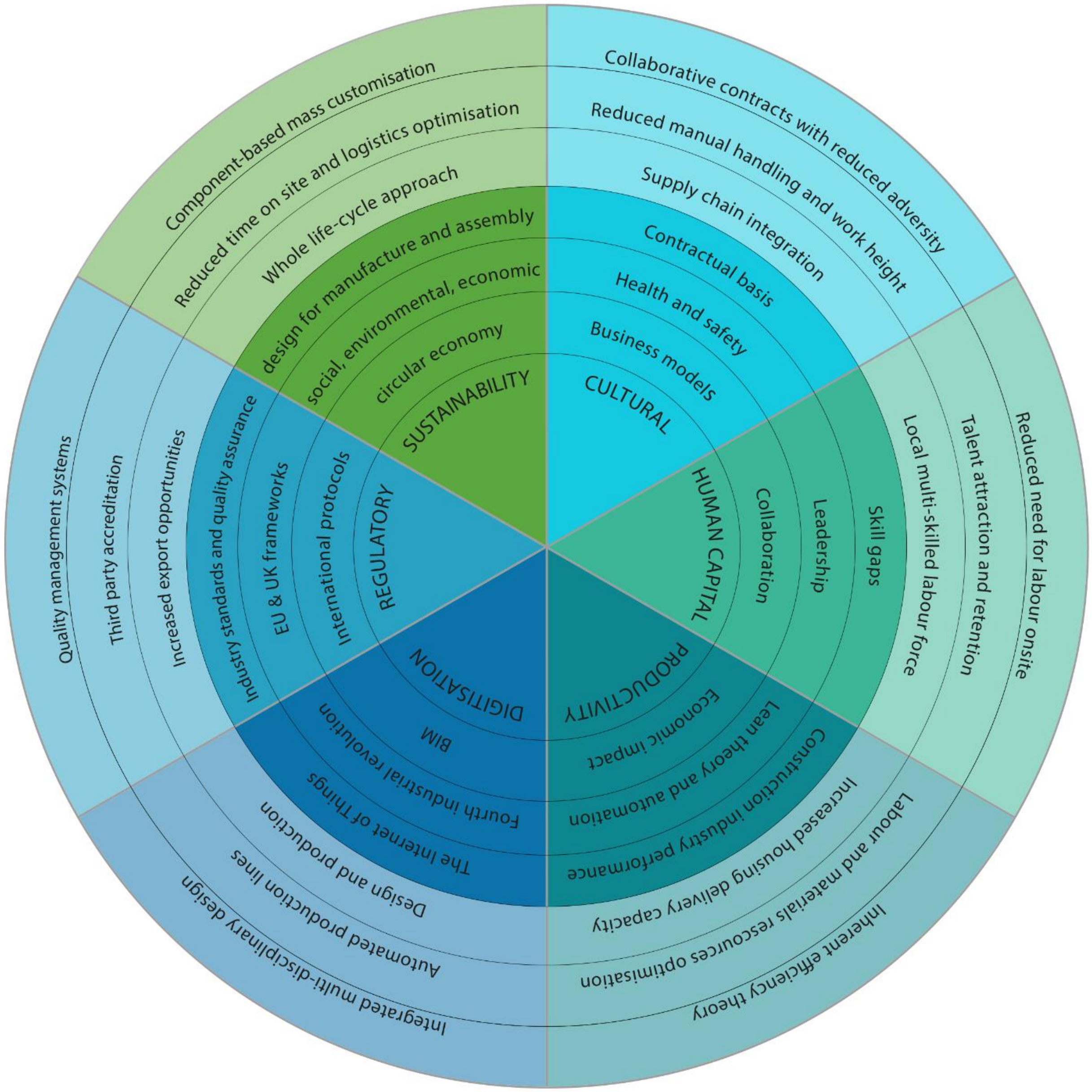

Figure 4. OSM decision-making tool: Layer 1, showing the drivers, factors and OSM reactions.

CONCLUSION

Overall, this paper theorised the main economic drivers for use of OSM and the reaction factors of OSM against each factor. This was combined with the novel field of infographic representation to develop a qualitative tool for decision-makers. Three main iterations were outlined, with varying degrees of complexity. Among these the colour-wheel concept was selected as the most suitable and intuitive. This tool, with future potential interactivity built-in, could be used to introduce the concept of OSM to key stakeholders who may not be familiar with the intricacies of factory-based construction and the advantages it could bring. The decision-makers could firstly identify their economic priorities and then easily identify which OSM aspects they could focus on to achieve their intended economic impact improvement. This could happen in any combination of drivers to allow flexibility and adaptability to varying contexts. With future work, the usability of the tool can be tested in real scenarios and its factors adapted and/or extended in accordance with feedback from users.

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