THE POTENTIAL OF DIGITAL TECHNOLOGY TO IMPROVE CONSTRUCTION PRODUCTIVITY

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Despite increasing adoption of digital technology in construction, productivity reports have remained disappointing. To develop insights into the reasons of this contradiction, the present paper suggests drawing on organisational competitiveness literature considering that the factors-affecting-productivity are conveniently captured within that literature. Through a questionnaire survey, the paper analyses the views of managers in the UK construction industry regarding the effect of Building Information Modelling (BIM) and Big Data Analytics (BDA) on organisational competitiveness. The results are then traced back to the factors-affecting-productivity for discussion. It is concluded that digitalisation enables performance improvements that can be tied to productivity gains, but this relies on the presence of certain skills and knowledge, which require training. It is also concluded that the lack of impact of digitalisation on some of the factors-affecting-productivity may be limiting the impact of digitalisation on the overall productivity, thus leading to a stagnating productivity.

Keywords: big data, BIM, competitiveness, digital technology, productivity

INTRODUCTION

Construction productivity has been reported as stagnating worldwide for several decades against the backdrop of an overall productivity growth in global economy (García de Soto *et al.,* 2018). While the construction industry has been repeatedly reported to be under-performing in terms of productivity, there has also been a growing trend of digitalisation that is fuelled by the argument that digital technologies improve the practices in construction (Zhan *et al.,* 2018). Motivated by this contradiction, the present paper questions the statement that construction productivity has not been improving over the last several decades.

To this end, the paper first identifies four broad categories of factors-affecting-productivity in construction through a review of the literature. These are (1) people, (2) logistics and operations, (3) communication and information management, and (4) regulative framework. The four categories together suggest that the impact of digitalisation on productivity must be studied as a complex and multi-faceted (i.e. organisational) phenomenon. Hence, through a review of the organisational competitiveness literature, the paper makes the case that analysing the impact of digitalisation on organisational competitiveness can help revealing the complex picture of how digitalisation effect on productivity. Building upon this argument, the paper presents the results of a questionnaire survey that draws upon organisational

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competitiveness literature to measure the level of enhancement achieved by the use of Building Information Modelling (BIM) and Big Data Analytics (BDA). In discussion section, the results of the survey are traced back to the initially identified categories of factors-affecting-productivity, thus developing insights into whether and how/where the expected productivity benefits of digitalisation accrue in practice. As a result, the paper informs the debate around construction productivity and scrutinises the argument that construction productivity has not improved over the last several decades. It shows that digitalisation can be tied to productivity gains in case skills and knowledge essential to exploit digital technologies as an organisation are in place.

Productivity and Organisational Competitiveness

As stated by Brynjolfsson and Hitt (1998), productivity is a simple concept: it is the amount of output produced per unit of input. However, a review of the literature on the factors-affecting-productivity reveals that productivity is the result of several interdependent components working together (see Table 1). This suggests that the impact of digitalisation on productivity must be studied as complex and multi-faceted (i.e. organisational) phenomenon.

Table 1: Summary of Factors Affecting Construction Productivity

Factors Affecting Construction Productivity	Category	Author(s)
Skills shortage; labour training and upskilling; leadership	People	Hasan *et al.,* 2018; Caldas and Gupta 2017; Lindhard and Larsen 2016; Böhme *et al.,* 2018
Unavailability of materials, proper tools, and equipment; unexpected materials; resource misallocation; inadequate risk assessment and mitigation, lack of supervision of operations; lack of labour supervision	Logistics and Operations	Hasan *et al.,* 2018; Abdul Kadir *et al.,* 2005; Kenley 2014; Naoum 2016; Zhan *et al.,* 2018; Khosrowshahi and Arayici 2012
Collaboration and coordination; stakeholder communication and coordination; communication of shared objectives; human-related delays in responding to requests for information	Communication and Information Management	Hasan *et al.,* 2018; Aziz *et al.,* 2013; Jarkas and Bitar 2011; Lindhard and Larsen 2016; El-Gohary and Aziz 2014; Makulsawatudom and Emsley 2004
Transparent policies, lack of certainty and continuity of work, compliance with standards, jurisdictional complexities, delays in permissions and permits, implementation of health, safety and environmental policies	Regulative Framework	Lindhard and Larsen 2016; Dai *et al.,* 2009; Aziz *et al.,* 2013; Matusik and Mickel 2011; Jarkas and Bitar 2011

The four categories of factors-affecting-productivity (see Table 1) are conveniently captured in organisational competitiveness literature (e.g. Porter 1985), thus suggesting that an analysis of the impact of digitalisation on organisational competitiveness can be traced back to understand the complex picture of how digitalisation affect productivity. Therefore, the remaining part of this section focuses on ‘organisational competitiveness’ to discuss the link between each of the four categories of factors-affecting-productivity and organisational competitiveness with references to the impact of digital technology.

People

‘People’ is widely acknowledged as an important determinant of organisational competitiveness in construction management literature. Lu (2006) claims that the workforce of a company is one of the greatest assets that create value for an organisation. Henricsson *et al.,* (2004) define a competitive organisation as the one with ‘satisfied employees’ claiming that satisfaction motivates employees to continuously contribute to an organisation. Further, Ericsson *et al.,* (2005) who discusses about a Total Value Competitiveness framework stresses that 'management skills' are critical determinants for organisational competitiveness, thus emphasising the importance of 'people'. The authors further specify the importance of institutions for training and development, thus pointing out to the criticality of investing in 'people'. Previous research also reported on the intersection of digital technology, people and competitiveness. Ross (1996), for example, shows how digital technology help enhancing firms' competitiveness by improving worker satisfaction; as innovative IT technologies could make day-to-day tasks more convenient while introducing them to new areas for training and development. Moreover, according to Betts *et al.,* (1991) when strategically approached, digital technology can be an enabling mechanism for the upskilling of employees. On the other hand, Harty *et al.,* (2007) claimed that evolving technology means shifted training and education requirements in construction, and that the different interpretations of the changing training and education needs would create people with different capabilities.

Logistics and Operations

The significance of 'logistics and operations' in an organisation is recognised in the organisational competitiveness literature. Henricsson *et al.,* (2004) point out that, in construction, management processes can be commercialized to be turned into improved performance leading to competitive advantage. This resonates with Buckley *et al.,* (1988) who noted that definitions and measures of competitiveness vary, and could distinguish three different views of competitiveness: the ability to perform well in terms of effectiveness (quality) and efficiency (speed) the endowment of assets (plant, material), and the ability to predict the future performance. Ericsson *et al.,* (2005) who examined the Total Value Competitiveness (TVC) framework acknowledged that 'technological ability' is a key when appraising the TVC. Further, Barney (1991) who analysed firm's opportunities and threats in its competitive environment referred organisational competitive advantage as a 'collection of resources' consisting of plant, material and equipment. Harty *et al.,* (2007) suggests that radical as well as incremental innovation has the potential to increase the competitiveness of a construction industry and show that research and development to increase 'innovation capability' has been mentioned in a number of competitiveness studies. Over the past decades, there has been no shortage of studies on organisational competitiveness focusing on the impact of digitalisation to logistics and operations. The use of information technology in construction is extending beyond the stage of piecemeal application for improving the daily-basis operational efficiency of discrete logistics and operations in individual organisations (Betts *et al.,* 1991). Singh *et al.,* (2011) assert that innovative IT solutions like BIM has the potential to profoundly change how construction is operated by stimulating the efficiency and effectiveness of information sharing among project stakeholders for the ease of logistics. Betts *et al.,* (1991) stresses that when the changes are managed carefully, IT significantly impacts on construction business.

Communication and Information Management

Research on organisational competitiveness in construction shows the importance of 'communication and information management'. Harty *et al.,* (2007) identify that having an 'information management system' and the 'ease of information abstraction' provides organisational competitive advantage as it supports well-informed and effective decisions. Wei *et al.,* (2010) studies the influence of information and communication capabilities for sustainable competitive advantage and identifies communication and information management as a determinant of competitive advantage due to their positive impact on efficiency. Further, based on the resources-based view of competitiveness, Bharadwaj (2000) affirms that, if information processing is integrated with other resources in an organisation, then an organisation could achieve time reductions and faster decision making, thus gaining competitive advantage. Several studies have outlined the benefits that construction organisations could achieve by using digital technology for ‘communication and information management’. Betts *et al.,* (1991) explain that strategic application of digital technology ensures that information can be effectively exploited by the users, thus enabling effective decision-making. Singh *et al.,* (2011) examine organisations that use digital technology and affirm that such organisations could expand and diversify their activities in several different ways, thus leading to faster and better decisions due to better communication and information management. Additionally, BIM literature is abundant with studies claiming various benefits of ‘communication and information management’ that increase competitiveness (e.g. Grilo and Jardim-Goncalves 2010).

Regulative Framework

A rightly tailored regulative framework, which governs and enables the organisation to conceive of and implement strategies, is likely to improve performance efficiency and effectiveness for competitive advantage (Betts *et al.,* 1991). The literature lists several attributes related to regulative framework that are important for enabling sustainable competitive advantage. For the purposes of this paper, such attributes can be conveniently classified into two: strategic governance (Betts and Ofori 1992) and collaborative partnering (Harty *et al.,* 2007). The extent to which digital technology intersects with the organisational regulative framework depends on the ways in which technology is used in an organisation (Betts *et al.,* 1991). Lu (2006) suggests that using digital technology in construction organisations leads to improvements in collaboration and co-ordination by enabling the contractors to develop effective executional frameworks with right business partners as well as allowing smaller contractors to compete against larger ones. On the other hand, Çıdık *et al.,* (2017) warn that digital technology may impose new ways of working on practitioners that might hamper collaboration. Additionally, contractual challenges of working with BIM is acknowledged in literature (e.g. Porwal and Hewage 2013).

METHODOLOGY

A review of organisational competitiveness literature revealed that (i) the four categories of factors-affecting-productivity have also been acknowledged as areas of critical importance for organisational competitiveness, and (ii) digital technology can have positive impact on these areas. Hence, insights from organisational competitiveness literature are used to develop a questionnaire survey to understand whether, and to what extent, organisational competitiveness has been affected by using BIM and BDA in terms of the issues relating to (1) people, (2) logistics and operations, (3) communication and information management, and (4) regulative framework. Inquiring into the impact of digital technology on competitive advantage through these four areas enables a rich discussion of how productivity might be affected by digitalisation as a result of complex interdependencies between different categories of factors-affecting-productivity.

The respondents of the questionnaire were chosen through a non-random purposive sampling effort. The respondents involved practitioners occupying managerial roles at various levels in the UK construction companies using BIM and/or BDA. The analysis follows a two-fold strategy. First, the enhancements relating to competitiveness as a result of using BIM and BDA are measured. Thus, the questionnaire asked its respondents to rate the level of enhancement achieved in each of criteria relating to the areas of 1) people, (2) logistics and operations, (3) communication and information management, and (4) regulative framework. A Likert scale was used in the questionnaire with a scale from 1 to 5 representing various levels of enhancement. Second, using a 4-point Likert scale, the respondents were asked to identify the level of importance of the skills and knowledge that are reported to be key for the exploitation of BIM and BDA by the literature. So, the second part of the analysis explored what skills and knowledge are essential in realising the claimed enhancements measured in the first part of the analysis. The second part also asked about the need for training on these essential skills and knowledge, now, and in five years. Thus, the second part of the analysis does not only reveal the skills and knowledge needed for addressing productivity issues through digitalisation but also reveals the practitioners' view about where the needs for training currently are, and where they are likely to be in five years.

ANALYSIS AND RESULTS

173 questionnaire forms were distributed. 63 usable responses were received which gives an average of 36.42% response rate for both BIM and BDA. Descriptive statistics were used to present the 'level of enhancement' of each criterion (see Table 2) alongside the mean and standard deviation of the answers. To measure respondents' perception on the level of enhancement for each criterion, the level of enhancement Index (LEI) formula was used (see Equation 1). The equation was derived from a similar formula computed by Chan and Kumaraswamy (2001).

$$LEI= \frac{5(n5) + 4(n4) + 3(n3) + 2(n2) + 1(n1)}{5(n1 + n2+ n3 + n4 + n5)} \quad \text{.... Equation (1)}$$

In this formula, n1, n2, n3, etc. refer to the total number of respondents who selected the corresponding rating in the Likert scale which ranges from 1 to 5. For example, n1 refers to the number of respondents who selected '1' in the Likert scale. The number of responses received for each number in the Likert scale are added-up, and then divided to the maximum possible value that could be achieved if all respondents gave a rating of '5'. When a question is not asked for BIM or BDA, this is indicated as 'not applicable' (N/A) in Table 2. Adopting the same formula, Table 3 shows the Degree of Importance (DII) of the skills and knowledge that managers need to possess to achieve enhancements in criteria listed in Table 2.

DISCUSSION

The results presented in Table 2 can be discussed from three perspectives: first in terms of the levels of enhancement in different categories, second in terms of the levels of enhancements of different criteria under a same category, and third in terms of the comparison of LEIs measured for BIM and BDA for a same criterion. Between the categories, the highest level of enhancement is measured in 'Communication and Information Management' due to BIM use (88.63% average LEI). This is in line with the dominant argument of BIM literature which suggests that BIM prevents the issues with unstructured and missing data that leads to productivity loss (El-Gohary and Aziz 2014). A similar high LEI is measured for the criterion measured only for BDA under this category suggesting that better insights into data improves communication and information management. However, when all categories considered together it is clear that there are mixed levels of enhancements caused by BIM and BDA.

Table 2: Level of enhancement in organisational competitiveness criteria

#	Criteria	Mean		Std. Deviation		LEI %	
		BIM	BDA	BIM	BDA	BIM	BDA
	PEOPLE						
1	Employee satisfaction / retention	3.22	3.34	0.75	0.69	66.27	66.88
2	Professional skills and judgement	3.53	3.47	0.64	0.56	70.59	69.38
3	Training and education processes	3.75	3.53	0.88	0.71	74.90	70.63
	LOGISTICS and OPERATIONS						
4	Research and development for innovation	3.25	3.31	0.84	0.63	65.10	66.25
5	Technological capability	3.67	3.75	0.70	0.66	73.33	75.00
6	Effectiveness of plant and materials	3.82	3.66	0.90	0.89	76.47	73.13
7	Speed and quality of delivery	4.78	4.78	0.50	0.41	95.69	95.63
8	Performance predictability	4.82	4.78	0.43	0.41	96.47	95.63
	COMMUNICATION and INFORM. MAN.						
9	Less rework and time due to early risk detection	4.29	N/A	0.77	N/A	85.88	N/A
10	Ease of creating and managing information	4.48	N/A	0.69	N/A	88.63	N/A
11	Better decisions due to better data insight	N/A	4.41	N/A	0.61	N/A	88.13
12	Effective collaborative decision-making	4.57	N/A	0.66	N/A	91.37	N/A
	REGULATIVE FRAMEWORK						
13	Company governance	2.61	2.69	0.97	0.98	52.16	53.75
14	Collaborative alliances and partnering	3.24	3.28	0.85	0.80	64.71	65.63

Table 3: Degree of importance of skills and knowledge (currently and in five years)

Skill and knowledge dimensions	Degree of Importance Index- BIM				Degree of Importance Index- BDA			
	Current		Future		Current		Future	
	Use	Need for Training	Use	Need for Training	Use	Need for Training	Use	Need for Training
Innovation Man.	73%	76%	72%	70%	68%	78%	67%	65%
Information Man.	68%	72%	75%	72%	70%	78%	78%	70%
Team Work	66%	71%	79%	63%	63%	75%	75%	58%
Strategic Planning	58%	72%	55%	62%	46%	67%	58%	58%
Risk Man.	55%	62%	58%	56%	52%	50%	45%	62%
Legislation Man.	54%	58%	52%	52%	50%	60%	40%	70%
Communication	53%	50%	51%	57%	48%	58%	57%	47%
Leadership	53%	62%	60%	62%	52%	70%	63%	50%
Decision Making	48%	62%	64%	55%	53%	68%	67%	64%
Performance Man	48%	55%	61%	43%	43%	50%	42%	52%

This raises the question whether relatively low enhancements in certain categories of criteria for organisational competitiveness could be interpreted as a lack of impact of BIM and BDA on factors affecting productivity in those categories. For example, literature on regulative factors are acknowledged as important for both productivity and organisational competitiveness but the measured level of enhancement for this category is significantly lower compared to the other ones. This is in line with literature which suggests that BIM creates regulative challenges in construction (Porwal and Hewage 2013). So, it could be the case that the lack of overall productivity growth is due to the lack of enhancement in certain categories of factors due to digitalisation which offsets or limits the enhancements in other categories.

When looked at different criteria within individual categories, another complex picture emerges. The highest LEI is measured for 'performance predictability' criterion by using BIM (96.47%) under 'Logistics and Operations' category. This result is supported by a study conducted by Khosrowshahi and Arayici (2012) concluding that 'predictability' nature of BIM is advantageous not only to determine project feasibility before capital is committed to a project, but also for project design, construction and operation as it lowers risks. This resonates with literature on factors affecting productivity under 'Logistics and Operations' category, such as 'supervision of operations' (see Table 1), thus implying that BIM significantly enhances some of the factors affecting productivity. In contrast, under the same category, 'research and development for innovation' scored significantly less both for BIM and BDA, 65.10% and 66.25% respectively. Considering Dubois and Gadde's (2002) argument that the lack of productivity growth in construction can be tied to lack of innovation is particularly relevant here. This is because the relatively low score for enhancement of 'research and development for innovation' then implies a lack of impact of digital technology on productivity. Overall, certain criterion under the same category scoring high and others scoring low raises the question whether it is possible to claim an overall productivity gain in individual categories of factors affecting productivity.

It is also interesting that the results show very similar behaviour between BIM and BDA when a certain criterion is considered. For example, both BIM and BDA scored relatively low for criteria under 'People' and 'Regulative Framework' categories, while scoring higher in 'Logistics and Operations' and 'Communication and Information Management' categories. This signals that although BIM and BDA could be used in a complementary way to further enhance some of the factors affecting productivity (e.g. those relating to 'Communication and Information Management'), other important factors (e.g. those relating to 'People') remain relatively less addressed even when they are used together. It is also interesting to see how BIM and BDA enhance the same criterion differently in one instance. For 'training and education processes' criterion under 'People' category, while BIM's LEI was measured as 74.90%, BDA's LEI was measured as 70.63%. This might be due to the fact that the construction industry is still in the nascent stage in terms of understanding the potential benefits of big data including the opportunities that it brings to upskill the existing workforce for efficiency improvements. However, it could also be the case that BIM provides a richer platform in comparison to BDA, thus enabling more opportunities for improved education and training leading to productivity improvements (e.g. Teizer *et al.,* 2013).

Finally, Table 3 shows that although BIM and BDA have the potential to contribute to organisational competitiveness that can be tied to productivity gains, this is dependent on the availability of certain skills and knowledge to varying extents. More specifically, Table 3 provides an overview of what is seen as critical skills and knowledge to achieve the enhancements on organisational competitiveness listed in Table 2 through the use of BIM and BDA, now, and in five years. In this sense, it can be interpreted as a picture of what skills and knowledge needs are in the industry, now, and in five years, to make improvements on a wide range of factors affecting productivity. Importantly, Table 3 also shows the perceived training needs by practitioners, now, and in five years, thus providing a picture of where the skills and knowledge gaps are currently, and where they are likely to be in five years. One important point is that there are several areas that scored above 60% in DII for current training needs, thus pointing out to a severe skills and knowledge gap in terms of exploiting BIM and BDA for benefits of productivity. This is in line with Singh *et al.,* (2011) who suggest that uptake of BIM Level 2 is still moving at a slow pace. The interesting point is that the skills and knowledge that scored the highest degree of importance have also received some of the highest scores in terms of the need for training. This implies that the practitioners think that there is a lack of skills and knowledge in terms of what matters most to create benefits of BIM and BDA. Another important point is that while Table 2 reports a relatively low level of enhancement for innovation, Table 3 suggests that 'innovation management' is a high importance area with a high need for training thus complementing the finding in Table 2. On the other hand, surprisingly, some of the criteria that scored high level of enhancement in Table 2, such as those under 'Communication and Information Management' category, are also reported as areas that are in high need of training. It may be that certain improvements in 'communication and information management' are realised as soon as BIM and BDA are implemented but there are further potentials for further exploitation.

CONCLUSIONS

The present paper has questioned the statement that construction productivity has not been improving over the last several decades despite ongoing digitalisation. The complex relationship between productivity and digitalization is explored through a questionnaire survey on the effects of BIM and BDA on organisational competitiveness which conveniently captures factors-affecting-productivity. Generalising from the results of the survey, it can be concluded that digitalisation can be tied to productivity gains when certain skills and knowledge essential to exploit digital technologies as an organisation are in place. It is revealed that it is important to embrace digitalisation as a multi-faceted (i.e. organisational) phenomenon to create productivity improvements. This is because the results raise the concern that the lack of improvement of overall productivity might be due to the interplays between various categories of factors-affecting-productivity some of which might have been relatively less or even negatively impacted by digitalisation. Considering that both BIM and BDA mostly impact on 'communication and information management' and 'logistics and operations', it can also be concluded that digitalisation must be complemented by improvements on 'people' and 'regulative framework' related issues. There is also evidence that practitioners require training even in the domains that are most enhanced by BIM and BDA, thus suggesting that there is still room for enhancement in already highly-enhanced areas. Further research needs to conduct a larger survey considering more criteria and skills/knowledge to validate and advance the findings of this study.

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