CONSTRUCTION PRODUCTIVITY AND DIGITALISATION: AN IT PRODUCTIVITY PARADOX PERSPECTIVE

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The construction industry has been going through digitalisation for several decades to improve the delivery of built assets. However, despite the ongoing investments in digital technology, productivity growth in construction has remained very low. This suggests that there is a need to better understand the relationship between digitalisation and construction productivity so that the desired productivity benefits through digitalisation could be achieved. A systematic literature review is conducted on the Scopus database to scan the publications that have made claims regarding the relationship between digital technology and construction productivity over the last ten years. The results are grouped into six categories based on the kind of claim they have made, and the key arguments of each group are examined. These key arguments are then discussed using the literature on the 'information technology productivity paradox' as the interpretive framework. The discussion suggests that digitalisation has not had the desired impact on productivity due to the lack of consideration for the interdependencies between various factors and levels of organisation affecting productivity. It is concluded that adopting a system-innovation perspective is crucial to enable meaningful productivity improvements through digitalisation.

Keywords: digital, information technology, productivity, paradox

INTRODUCTION

Over the last few decades, the construction industry has been going through digitalisation to improve the delivery of built assets (Ibem and Laryea 2014). However, productivity growth in construction has remained very low (McKinsey and Company 2017) despite the digital-driven changes in deliverables (RIBA 2013), production and collaboration processes (Shen *et al.,* 2010), as well as professions (Jaradat *et al.,* 2013). Therefore, there is a need to understand the reasons behind the lack of impact of digital technology investments on construction productivity. Such an understanding is key to realising the desired productivity improvement through digitalisation.

This paper draws upon a systematic literature review (SLR) to develop insights into the reasons why digitalisation has not had the desired impact on construction productivity. Considering the limitations of the existing production theory in construction (Koskela and Vrijhoef 2001), the SLR asks the very basic question of 'how does the use of digital technology affect productivity in construction?' to

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generate insights into the relationship between digitalisation and productivity. Scanning the last ten years of the Scopus database, the SLR captures the papers that have made a claim regarding the relationship between productivity and digital technology in construction, and groups them according to the kind of the claim made. The findings of the SLR are discussed drawing upon the wider literature on the 'information technology (IT) productivity paradox' (Macdonald *et al.,* 2000) to propose potential explanations for the lacking impact of digitalisation on productivity in construction. The discussion suggests that digitalisation efforts fail to adequately consider the interdependencies between various factors and levels of organisation affecting productivity; thus, falling short in delivering the expected productivity improvement. It is concluded that both research and practice need to adopt a system-innovation perspective in order to enable the desired productivity improvement through digitalisation.

The notion of an 'IT productivity paradox' refers to a situation where significant investments in digital technology do not lead to meaningful improvements at aggregate levels of measured productivity (Macdonald et. al. 2000). Although under-explored in construction research, the notion was highly debated in the 1980s and 1990s in economics and management research with regard to the manufacturing and service industries. For this reason, the literature on 'IT productivity paradox' is reviewed in this section to be later used as the interpretive framework for the discussion of the findings of the SLR. The debate on IT productivity paradox can be traced back to Roach's (1987) seminal work which investigated the reasons behind the productivity growth slowdown that started in the 1970s. Significant in Roach's (1987) work was the distinction between an 'information worker' who mainly worked with information using IT, and a 'production worker'. Roach (1987) claimed that information workers were largely responsible for the slowdown by showing that, between 1970 and 1986, information worker productivity had fallen, or grown less than production worker productivity. Roach (1987) concluded that the remarkable increase in computerisation had had very little effect on economic performance, particularly in sectors that involve large numbers of information workers. Baily and Chakrabarti's (1988) work provided further insight into the issue as they suggested that information capital is a driver for employing more information workers rather than a substitute for information workers; hence relative productivity drops. In line with this argument, Osterman (1986) claimed that lower cost of information leads to higher demand, which then leads to an additional demand for information workers.

A decade later, Brynjolfsson and Yang (1996) reviewed the previous work on the IT productivity paradox and warned that the failure to demonstrate a productivity improvement from IT investments might not mean that IT was not contributing to productivity. The authors suggested four possible explanations for the disproportion between the technological progress and productivity growth which, since then, have been widely cited in IT productivity paradox literature. These are 1) mismeasurement of outputs and inputs, 2) lags due to learning and adjustment, 3) redistribution and dissipation of profits, and 4) mismanagement of information and technology. Mismeasurement of outputs and inputs implies that "traditional measures of the relationship between inputs and outputs [may] fail to account for non-traditional sources of value" (Brynjolfsson 1993, p.3). Lags due to learning and adjustment mean that there may be a significant time lapse between cost and benefit of technological progress, which creates productivity puzzles in the short-term (i.e. first decades of technological change) in relation to increasing computerisation. Redistribution and dissipation of profits account for the idea that "those investing in the technology benefit privately but at the expense of others, so no net benefits show up at the aggregate level" (Brynjolfsson 1993, p.4). Finally, the mismanagement of information technology argument suggests that "we have systematically mismanaged information technology: There is something in its nature that leads firms or industries to invest in it when they shouldn't, to misallocate it, or to use it to create slack instead of productivity" (Brynjolfsson 1993, p.4).

In line with these points, in later works of Brynjolfsson and Hitt (1996; 1998) it was argued that paradox was resolved as they looked at more recent and firm-level data and found correlations between firm-level IT investment and productivity. The clearer correlation between less aggregated productivity data and IT investments suggested that "computerization does not automatically increase productivity, but it is an essential component of a broader system of organizational changes which does increase productivity" (Brynjolfsson and Hitt 1998, p.55). However, despite the cheerful news on the resolution of the paradox in late 1990s and early 2000s, several studies in the literature still claim that the IT productivity paradox has not been resolved, or has merely changed form (e.g. Acemoglu *et al.,* 2014; Hajli and Sims 2015; Van Ark 2016; Polák 2017; Brynjolfsson *et al.,* 2017).

Perhaps the most encompassing discussion of the issue came from Macdonald *et al.,* (2000) who attempted to summarise the debate on the IT productivity paradox. The authors recommended to see the paradox as a matter of innovation, which can be grasped through an analogy between R&D investments and IT investments. According to this, just like R&D investments, IT investments should be seen as a part of the infrastructure required for innovation and competitiveness; and therefore, there cannot be specific calculations of output of IT investments (Macdonald *et al.,* 2000). The authors explained that this perspective would do justice to the extremely complicated issue of the IT productivity paradox, which could not have been resolved with new productivity measurement techniques or generic managerial recipes, such as business process reengineering. Thus, the authors criticised the emphasis on IT-based efficiency improvements by policy-makers and IT developers that advocated ever-increasing use of IT without necessarily understanding the nature of information and importance of innovation. Macdonald *et al.,* (2000) suggested replacing this with an emphasis on IT-based flexibility to promote innovation. They also cautioned against management consultants and fads that mostly neglected that innovation could come in many disguises and sizes depending on the unique circumstances of individual firms.

METHODOLOGY

This research draws upon a systematic literature review (SLR) to generate insights into the reasons why digitalisation has not had the desired impact on productivity in construction. According to Boell and Cecez-Kecmanovic (2015), SLR is a protocol-based approach to literature review which details the steps and processes of searching literature for objectiveness, rigour, replicability, and transparency. SLR is particularly suitable for providing answers to specific questions such as how one variable is related to another (Boell and Cecez-Kecmanovic 2015). Following from this argument and considering the limitations of the existing production theory in construction (Koskela and Vrijhoef 2001), the research question (RQ) for the systematic literature review is set as; 'how does the use of digital technology affect productivity in construction?'. This question enabled the SLR to consider all publications that claimed a relationship between productivity and digital technology in construction, and the grouping of these publications based on the kind of relationship claimed. Ultimately, such a grouping enables a rich discussion that considers various aspects of the relationship between productivity and digital technology, thus providing fresh insights into the reasons behind the lack of impact of digitalisation on productivity.

The Scopus database was searched for the SLR. The search query string used was "TITLE-ABS-KEY (construction AND (bim OR "building information modelling" OR "building information modeling" OR digital* OR technolog* OR artificial OR "bigdata" OR internet OR online OR web* OR machine OR computer*) AND productivity AND (measur* OR statistic* OR analys* OR increas* OR improv* OR high*))". This search query string returns all articles that include the words 'construction', 'productivity', one of the words relating to a digital technology (i.e. the words listed between 'bim' and 'computer*' in the string above), and one of the words relating to the relationship between productivity and digital technology (i.e. the words listed between 'measur*' and 'high*' in the string above) at the same time. These words were searched in the titles, abstracts and keywords of the articles. Following the initial search, the results were limited to journal articles in English that were published online between 01 January 2010 and 03 April 2019 (i.e. last ten years) due to time and resource limitations of the researcher. The remaining results were then filtered by the subject areas of 'engineering', 'business, management and accounting', 'social sciences', 'computer science', 'economics, econometrics and finance', 'decisions sciences', and 'multidisciplinary' to be made relevant to construction. 625 articles remained after these steps. The initial screening was done on the Scopus's search results page by reading the titles and abstracts of the remaining articles. In line with the RQ, only studies that claimed, and/or referred to, a relationship between digital technology and productivity were included. Papers were excluded if they only looked at the inner production processes of manufacturers in the construction supply chain.

The initial screening reduced the number of studies to be considered down to 130, which were then downloaded to, and managed in, RefWorks. At this point, the papers were grouped as below according to the kind of the claim that they make regarding the relationship between digital technology and productivity. The grouping was done based on a re-reading of the abstracts and main arguments/findings of the papers.

1. Papers that discuss the critical factors for performance and productivity (n= 9)
2. Papers that discuss methods/approaches for productivity/performance measurement (n= 36)
3. Papers about the use of digital technology for productivity monitoring, optimisation, planning and modelling (n= 40)
4. Papers that claim productivity improvement through the use of digital technology but do not engage in any measurement (n= 31)
5. Papers that claim measured productivity improvement through the use of digital technology (n= 10)
6. Papers that study the use of digital technology from a system-innovation point of view to refer to productivity improvements (n= 4)

Following the grouping, the papers were re-examined to identify the key arguments in each group of literature in relation to the RQ. Finally, the groups were paired (i.e. Group 1 and 2; Group 3 and 4; Group 5 and 6) to provide a better overview in the discussion of findings. In the next section, the key arguments identified from each group are first presented in pairs, and then discussed in relation to the IT productivity paradox literature presented earlier in the paper. This generates insights into the reasons why digitalisation could have failed to improve productivity in construction. Due to space limitations not all the reviewed articles could be included in the following section; and therefore, only the most relevant ones are discussed.

FINDINGS AND DISCUSSION

Papers on factors affecting productivity (Group 1), and measurement of productivity (Group 2)

The studies concerned with factors affecting productivity imply that digital technology has a positive impact on productivity, claiming that areas extensively addressed by digital technology, such as design quality and planning, are critical to productivity (e.g. Jarkas *et al.,* 2015; Naoum 2016). On the other hand, the difficulty of understanding the dynamics of labour productivity, particularly at an aggregate level, are acknowledged, for example, in Yi and Chan (2014), and Naoum (2016). Therefore, the argument is put forward that further critical research is needed to better understand the interplays between various critical productivity factors such as technology, management, innovation and labour composition considering the interdependent levels of task/activity, project, firm and industry (Goodrum *et al.,* 2011; Yi and Chan 2014; Naoum 2016; Pan *et al.,* 2018)

In line with these calls for further research, a few studies in the second group show that growth in Total Factor Productivity, which is regarded as the main driver of labour productivity growth (McKinsey and Company 2017), is affected differently by changes in technological progress, technical efficiency and scale-mix efficiency for different companies/regions/countries (Chiang *et al.,* 2012; Chancellor and Lu 2016; Azman *et al.,* 2019). These studies suggest that in most cases technological progress seems to increase labour productivity (see Kapelko and Abbott 2017 for an exception). However, more interestingly, they also suggest that meaningful productivity increases are possible by increasing technical efficiency and/or adjustments on scale-mix efficiency, depending on the particularities of a company/region/country. Leviäkangas et al.'s (2017) work is relevant here as they observe that the correlation between ICT investments in construction and construction productivity is weak when using industry level data from national accounts.

These arguments resonate with the studies that have suggested developing productivity measures which consider the quality of inputs and outputs, not only to better capture the real contribution of the changes in the industry (Sands 2010; Horta *et al.,* 2010), but also to understand what kind of innovations would have the largest/most disruptive positive impact (Bröchner and Olofsson 2012). Studies that have aimed to capture the productivity losses and gains due to certain organizational, communicational and managerial issues that can be related to IT use can also be seen as part of this effort (e.g. Cheng *et al.,* 2015; Park and Lee 2017). Furthermore, as opposed to the common assumption, Bröchner and Olofsson (2012) stated that, when it comes to innovation, the construction industry has more similarities to service industry than to manufacturing industry. This argument deserves further investigation considering the discontent about the explanatory power of existing productivity measures which hampers innovation in the industry.

Overall, looking at the studies in these groups, it seems like there is an agreement on the importance of technological progress to improve productivity, but also an acknowledgement that technological progress needs to be an enabler for systemic innovation. There is a lack of understanding on what to aim for regarding technological progress due to the lack of understanding regarding the interplays between various factors contributing to productivity at different levels of organization. This situation raises a red flag as it resonates with the IT productivity paradox literature which warns that when decision-makers in firms did not know what to do with technology, technology developers and management consultants tended to steer the change, leading to unsuccessful technology applications (Macdonald et. al 2000).

Papers on productivity monitoring, optimisation, planning, and modelling (Group 3), and papers claiming unmeasured productivity gains (Group 4)

These two groups cover the biggest number of papers with a total n= 71 (out of n= 130). The findings of the SLR suggest that technologies for task-level and project-level productivity monitoring, optimisation and planning attract significant attention, particularly in the area of earthworks in which automation is widely debated (see Azar and Kamat 2017 for a review). Also, there are several studies on productivity modelling (e.g. Lee *et al.,* 2014; Gerek *et al.,* 2015), which seems to benefit from the increasing processing power of computers. Considering that adequate planning has been identified as a critical productivity factor alongside site management (e.g. Naoum 2016), these studies are supposed to have a positive impact on productivity in practice by also addressing the ongoing challenge of establishing baselines for productivity in construction (Jarkas and Horner 2015; Yi and Chan 2014).

On the other hand, there is a considerable number of articles that claim productivity gains from digital applications that improve various tasks and processes during design and construction. These spread along a wide variety of focus and scope, ranging from the benefits of general concepts, such as using digital applications in construction (Liu *et al.,* 2017), via managerial domains, such as site management using mobile computing technology (Teo *et al.,* 2016), to specific issues, such as design error reduction using BIM (Wong *et al.,* 2018). Like the papers reporting improvements for productivity monitoring, optimisation, planning and modelling, the studies in this group address issues that were previously established as critical for productivity, which is what their claim for 'potential' productivity increase builds on.

With the IT productivity paradox literature in mind, for these two groups of paper, the question becomes whether (and how) the reported improvements addressing individual tasks/functions/domains in construction can actually enable meaningful overall productivity improvements. This is an important question considering Roach's (1987), Baily and Chakrabarti's (1988) and Osterman's (1986) arguments about the nature of information capital and the information worker. It is difficult to disagree with Nath *et al.,* (2015) (from Group 4), who argue that identifying and addressing inefficient points in production are crucial for re-organising processes in a more efficient way with the help of digital technology. However, if the ultimate aim is to improve overall productivity, then perhaps it is time to also start thinking about how digital technology could be used to develop flexibility of production for innovation, instead of creating isolated efficiency improvements that might merely lead to organisational slack, as cautioned by the IT productivity paradox literature (e.g. Brynjolfsson and Yang 1996).

Papers claiming measured productivity benefits (Group 5), and papers studying the use of digital technology from a system-innovation point of view (Group 6)

Similar to the studies discussed in the previous sub-section, papers demonstrating measured productivity improvements also vary in their scope and foci. However, two additional insights seem to be enabled in these studies in terms of (i) the extent to which productivity increased, and (ii) the enablers and barriers of the identified productivity improvements, which were revealed by putting the proposed solutions into practice (e.g. Zekavat *et al.,* 2015; Yamaura and Muench 2018; Hwang et. al. 2019).

Also, the SLR returned a small number of papers that study the use of digital technology from a system-innovation point of view. Although these studies are lacking the vivid details of the papers claiming measured productivity benefits, the two groups are similar in their conceptual richness. Articles that study the use of digital technology from a system-innovation point of view provide a conceptual picture within which studies that address more specific areas can be interpreted. In this group of papers, while Holmström *et al.,* (2014) study BIM as infrastructure, Aksenova *et al.,* (2018) suggest understanding BIM deployment through an ecosystem lens. Furthermore, Dowsett and Harty's (2018) work, which employs an information systems approach to BIM implementation, considers company-level and project-level aspects of BIM implementation in tandem, thus exposing how focusing on only one of these levels creates a simplified view of BIM leading to unsuccessful results. Finally, although more empirical in its approach, the work of Ahn *et al.,* (2016) also reveals the multiple dimensions that a contractor needs to consider in order to gain meaningful benefits from BIM, thus implying the need for system-innovation.

In line with Macdonald et al.'s (2000) reflections on the IT productivity paradox literature, the papers in these two groups confirm, in a complementary way, that meaningful overall productivity gains from using digital technology depend on the extent of the innovation achieved in the respective (i.e. information, socio-technical, and so on) system. This is also in line with the arguments presented by the studies looking at critical factors of productivity and studies concerned with productivity measurements and trends in the industry (see above). Therefore, the studies reporting measured productivity gains and system-innovation perspectives are likely to help researchers and practitioners refrain from unrealistic expectations from digital technology and drive more realistic innovation agendas to create meaningful productivity gains through digitalisation.

CONCLUSIONS

Despite the increasing number and variety of digital technology in construction, the disheartening results of construction productivity reports have remained the same over the last two decades. Motivated by this phenomenon, this paper has set out to discuss the relationship between digitalisation and construction productivity by drawing upon the insights enabled by the IT productivity paradox literature. An SLR was conducted on the Scopus database, grouping 130 articles into six categories; subsequently, each group was re-examined to explore the effects of digital technology on productivity.

Although this paper is limited in its scope and extent, and thus the arguments made here must be further validated, some interesting points have emerged to generate debate. It is found that articles studying measurement techniques and critical factors for productivity reveal not only issues of mismeasurement, as also highlighted by the IT productivity paradox literature, but also misguidance due to mismeasurement. Also, the present paper has found that there is a major interest in conducting studies focussed on a specific task, function, etc., claiming productivity gains from digital technology without however systematically measuring it. When these two findings are considered together, the concern rises that, at an aggregate-level, digitalisation in construction may not be contributing to productivity as expected. In conclusion, both productivity improvement and digitalisation agendas need to adopt a system-innovation perspective to adequately consider the system-level implications of digital solutions so that productivity improvements could be enabled at an aggregate-level. This implies the need for more conceptual work relating to production in construction as well as theoretically-informed practical experiments with potential digital solutions.

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