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A conceptual framework for measuring productivity and performance in Industry 5.0: A built environment perspective

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A Conceptual Framework for Measuring Productivity and Performance in Industry 5.0: A Built Environment Perspective

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Abstract
The construction industry in most countries is an early indicator of the nation's economic health. When things are buoyant and the construction market is booming, it indicates the state of the viability of the country's economic position. The model used in measuring productivity since WWII (e.g., labour productivity, GDP per capita, multifactor productivity) does not seem suitable for the emerging industry 5.0 (I5.0), considering the prevailing factors within the Built Environment (BE). These metrics are optimised over the years to provide detailed and comprehensive insights into productivity trends and drivers, which lacks necessary attributes to measure productivity and performance in the context of I5.0 and the emerging future world. This paper employs a Scientometric analysis to understand the prevailing factors within the identified body of knowledge of measuring productivity in the BE. This is fed into the Cobb-Douglas function to develop a conceptual framework that redefines productivity measurement for the emerging I5.0 within the BE context. Through these methods, we identify key criteria for measuring productivity holistically, considering the intertwined effects of technological innovation, the UN's Sustainable Development Goals (SDGs), and circular economic (CE) principles on construction industry performance. Our findings underscore the limitations of conventional metrics when applied to I5.0, highlighting the need for new units of analysis to facilitate meaningful improvements. This research proposes an extended productivity measure matrix that aligns with sustainable development, human-centric systems, and resilience-building initiatives, offering a pathway for more effective monitoring and enhancing productivity in the built environment.

Keywords
Built Environment, Circular Economy, Industry 5.0, Productivity, Sustainability.

1 Introduction

The construction industry operating within the Built Environment (BE) is usually considered a laggard when it comes to innovation to improve productivity and performance that will be at par with allied industries like manufacturing, automobile, and aerospace. Even innovations that allied industries have perfected are ripe for exploitation and adoption within construction, there is inertia by construction practitioners, academics, and stakeholders in the way this is done. Some experts and practitioners attributed some of these factors of inertia to the construction workers' lack of skills and competencies compared to the other industries. Others attributed this to how the industry developed from antiquity to now, which is more evolutionary in nature and not in line with the transformative nature required going forward. If growth is to be realised in the construction industry, productivity throughout the industry needs to be injected with better innovative approaches driven from the top right down to the shopfloor level by industry leaders.

Productivity in any industry can be viewed from multiple perspectives; however, it is still best to start from the most fundamental of definitions, which is usually the output realised divided by the input to the production of individuals within that industry. Viewing productivity in this basic form works particularly well at all levels of industry, organisational, operational, and individual worker's level. For productivity to be assured, understanding where productivity in construction lies is expedient. To close the current gaps associated with construction productivity problems with innovative solutions, modern factors impacting on construction and other BE industries like manufacturing should be investigated. Factors like Building Information Modelling (BIM), Virtual Reality, Augmented Reality, Automation, Artificial Intelligence (AI), Sustainability factors, and Circularity Economics (CE) need better understanding from professionals and practitioners in the construction domain. Thus, understanding these productivity issues, impacting factors, and finding ways to solve them is the aim of this research paper.

The remainder of the paper follows a standard formatting style containing the following sections. Section 2 contains a comprehensive literature review to understand the prevailing factors influencing productivity within the construction context, and section 3 the research methodology that was used in relation to the Scientometric analysis and development of the Cobb-Douglas function. Section 4 brings the findings together from the Scientometric analysis, and section 5 provides the underpinning justification for developing the conceptual framework, considering the development of the industry's productivity.

2 Literature Review

2.1 Productivity in Construction

While productivity in most BE industries like manufacturing, services, and aerospace has been growing year on year, it may appear that productivity within the construction sector has seen slow growth for an exceptionally long time. Even with the introduction of ICT systems that enhanced labour productivity in the early eighties to now, in various forms, it still appears to be flatlining in most cases. Labour productivity in construction is a significant indicator for measuring the sustainable development potential and competitiveness of a nation's production and growth potential. Under the background of the integration of the global construction industry and information and communication technology (ICT), the pursuit of the growth of construction labour productivity (CLP) requires a better appreciation of how these technological advancements characterised by ICT as the start, take effect in the change of CLP as well as what the key factors that led to the variation of CLP at this stage.

There are many factors that are essential for productivity growth in an industry, as well as within the organisations that contribute to effective organisations and efficient industrial growth. Some of these factors are mirrored in the construction industry productivity. In a generic way, these factors can be summarised under two broad subheadings: technological and non-technological factors. With such a broad remit, distinct categories of factors can be developed so that most of the essentials that will address productivity growth in the modern world can be addressed (Rathnayake et al., 2024).

Some key factors that do impact organisational productivity are the learning culture and the impact of these on the organisational performance, which may lead indirectly to productivity improvement and innovation within that company. The top priority for the nation at this time is to create a widely shared consensus about the need for increasing growth in national productivity. The basis for such a consensus is the existence of a direct link between growth in productivity and the personal economic well-being of the population (Posillico et al., 2023). Under the present social circumstances, attempts have been made to increase productivity while considering a low leverage for social benefits. Emphasis should be shifted from the productivity of actual local production units to the productivity of the society. We should identify the social, legal, technological, and cultural issues driving the economy towards national inefficiency and take a short-term view of events.

The development of new concepts and inventions is the basis of all improvement in human endeavour. Productive work is the aggregate, efficient use of all resources, including the knowledge and creativity of management and professional personnel. Profit must be factored in to sustain the future operations of the enterprise.

However, when LP is considered not directly as contributing just to the physical work of the individual but also to issues of intellectual property (IP) and competencies that are more intangible, then understanding productivity is subtle. Therefore, the models used to address productivity in construction should also include subtle and emerging issues that make improvement to productivity possible in the twenty-first century. This is where the digital space comes into play, with all its possibilities of improved production, as well as considering all the associated risk factors and sustainable issues in the construction process (Christopher & Thor, 1993).

2.2 Sustainability in Construction

Sustainability concepts have been paramount in identifying green initiatives in resource extraction and responsible consumption during the past few decades. As a result, concepts such as disaster resilience, digitisation, CE, IOT, Industry 4.0 (I4.0) and Industry 5.0 (I5.0), as well as global initiatives such as the Sustainable Development Goals proposed by the United Nations, have been developed to further underpin sustainability (De Giovanni, 2023; Ghobakhloo et al., 2022; Marzouk & Elmaraghy, 2021; Sánchez-García et al., 2024). BE is currently undergoing a paradigm shift of innovations to cater to these sustainability concepts and move towards a greener and zero-waste approach. However, studies show that these implications are not holistically explored to understand the consequences and the impacts of each of them. As a result, concepts such as I5.0, circularity, and SDG alignments are limited within the identifiable body of literature.

I5.0 has evolved to be value-driven rather than its technology-driven counterpart (I4.0) and focuses very much on human-centric collaboration (Grosse et al., 2023; Zengin et al., 2021). As it is a paradigm shift from automation to human-centric active participation, a key emphasis is on utilising resources and making overall production and manufacturing processes much more efficient. This has further integrated sustainable thinking such as Lean, where minimising waste and maximising productivity is crucial in human- and material-centric contexts. It further justifies the popularity gained by end-of-life usage, such as design for disassembly, and analytical models, such as Life Cycle Assessment (LCA), in evaluating resource efficiency and waste reduction, as well as understanding the overall environmental impacts throughout the intended life cycle of a product (Garrido et al., 2024; Leng et al., 2023). For example, it is very much best practice within a built environment to conduct LCA in assessing the overall impacts of a building's design lifespan.

The efficacy of sustainability concerning the current underlying factors of I5.0 includes SDG initiatives. It is evident that the blueprint of I5.0 has been generated to address all seventeen goals and encompass sustainable economic growth within the production and manufacturing sector as a whole (Ghobakhloo et al., 2022). However, literature identifies prominent emphasis on two SDGs, namely SDG 9: Industry, Innovation, and Infrastructure, and SDG 8: Decent Work and Economic Growth (Dixson-Declève et al., 2022; Farsi & Erkoyuncu, 2021). The key focus on industry and sector-related potentials and innovations are influential; case studies signpost the integration of digital transformation and other sustainable solutions, such as circular economics in building resilient infrastructure and promoting greener construction (Gomis et al., 2023; Ikudayisi et al., 2023; Xu et al., 2021). Concepts such as BIM, 3R-principal adoption, modern methods of construction (MMC), and LCA, which have gained popularity over the past few decades, validate these implications within the construction and the overall BE sector. Conversely, I5.0's human-centric approach indicates and promotes human-led initiatives, whether it be more job creation (social sustainable parameters) or aligning circular models such as product-as-a-service (PaaS) or merely to a collaborative extends (Farsi & Erkoyuncu, 2021; Sindhwani et al., 2022). It is again signposted in innovative macro-level economic models such as industrial symbiosis, which has underpinned collaboration and networking at its core and is considered crucial in its pathway towards sustainable industries.

2.3 Digital Technology (DT)

Before discussing I5.0, it is best to consider I4.0; as of now, most of the literature that is out there is still developing (Ganah & John, 2023). I4.0 has fundamental weaknesses, including the lack of human centricity. By this, practitioners and academia believe that stakeholders use mostly technological innovations, which are developing the use of, or consisting of advanced ICT, BIM, IoT, digital twins, automation, robotics, AI, and less well-known innovations for collaborating. Other essential issues that are developing in parallel to I4.0 have not yet been mentioned or considered for consideration. In the 'spirit' of allowing the continued enhancement of I4.0, a new terminology called I5.0 emerged, focusing on the main fundamental weakness, which is the human-centric nature. With such an approach, by incorporating human subjectivity, a new understanding can develop, which will consider how the industry, organisations, and individuals in general will work. Such work usually occurs through continued collaboration in all its various guises. I5.0 is about promoting the ethics of technologies and making industries sustainable (Farsi & Erkoyuncu, 2021) by enhancing big data analytics.

Chen et al. (2021) explored the concept of a human-cyber physical system (HCPS) in the context of I5.0 technologies. Alvarez-Aros & Bernal-Torres (2021) independently conducted a systematic review of technological competitiveness and the emerging technologies of I4.0 and I5.0. Their research shows that the top three technological elements for developing economies are smart manufacturing, IoT, and organisational structure for sustainability. Meanwhile, for developed economies, the element of 'big data analytics' is next to the former two elements. However, one area not explored so much in all of these papers and research ideas is the circular economy, which will give a better holistic understanding of what is required with the built environment for a sustainable approach to productivity and performance. Thus, the three core values of industry are sustainability, human centricity, and resilience. The way the industry is evolving due to all these innovations needs a better understanding of how productivity and sustainability are viewed, with the added caveat of a CE approach coupled together (Gomis et al., 2023).

Therefore, it is imperative that organisations in the BE, more so construction firms, despite lagging in appreciating changes in I4.0 (i.e., BIM, automation in work processes), the organisations will have to grapple with the new factors posed by I5.0. Transitioning from what is familiar, like BIM, to innovative technologies and usage, as stated in I5.0, will have a significant impact concerning productivity and performance. Using manufacturing as a comparator, I5.0 offers a 'game changer' to all the organisations that will be transitioning to the new understanding of the evolving productivity in the

BE marketplace. This marketplace will reflect the new reality of sustainable understanding, CE, and issues of diffused technological embedment. The transition will be gradual and may not be noticeable for the first few years if the correct data collection and analysis are done.

3 Research Methodology

The methods following the investigation of literature contain a Scientometric analysis and development of a conceptual framework using the Cobb-Douglas function. The literature review captures the knowledge and understanding that influence how productivity in the construction industry is developed. Major themes emerging from the general literature gave a better viewpoint of what should be addressed and what is common to other industries within the built environment. This was fed into the Scientometric analysis, which included publications since 2014, in identifying trends and factors that contribute to productivity within the BE. These trends and factors were entered into the Cobb-Douglas function in developing a conceptual framework for measuring productivity within I5.0.

3.1 Determinants of Productivity

The data collection process began with an extensive Web of Science database search, focusing on articles relevant to I5.0 and the built environment. A search string ["built environment" (Topic) and "sustainab*" OR "productiv*" OR "industry 5.0" (All Fields) and "construction" (All Fields)] was used to identify pertinent literature. The initial search yielded a broad range of articles, which were subsequently filtered to refine the sample size of 1818 journal article entries. The filtration process involved a rigorous screening of the retrieved articles to ensure relevance and quality. The inclusion and exclusion criteria included removing duplicate entries to avoid redundancy, articles published only in English and the publication date, where preference was only given to recent publications from 2014 to ensure the timeliness of the data. After applying these filters, a final sample of articles was established, forming the basis for further analysis using VosViewer for Scientometric analysis. The filtered sample identified key themes related to productivity and performance in I5.0. This thematic analysis involved a detailed review of the selected articles, focusing on recurring concepts, methodologies, and findings (Gomis et al., 2023; Zhong et al., 2019). The identified themes were essential for understanding the various dimensions of productivity and performance within the BE sector under the I5.0 paradigm.

A Scientometric analysis was adopted to study and measure aspects of scholarly articles. Scientometric analysis is a quantitative method used to analyse research progress, its influence, impact, and association within the scientific literature (Zhong et al., 2019). Although scientometric analysis could be conducted to assess citation counts and research output from authors, organisations, and journals, this study only focused on identifying the impact of keywords. Thus, a keyword count was done by a co-occurrence network mapping to obtain the overlay visualisation that assisted in identifying factors and categories that were fed into the conceptual framework development. From an overall 6573 set of keywords, only 42 met the minimum threshold with the minimum number of 35 occurrences of a keyword. The occurrence was solely developed for the ease of understanding the factors and the categorisation within the overlay visualisation. This was further used to understand the link strength of each keyword, how impactful they are in broader knowledge, and the categorisation of each keyword to identify the appropriate clusters.

The keyword categorisation obtained through cluster classifications was fed into the development of the conceptual framework using the Cobb-Douglas function, which describes the amount of output changes based on the inputs used in a production system. The Cobb-Douglas production function is a widely used mathematical economic model that describes the relationship between inputs (i.e., typically labour and capital) and the output of goods and services. In this study, the Cobb-Douglas function was used to conceptualise how different productivity drivers identified through Scientometric analysis within the trends of sustainability practices, CE practices and digital technology contribute to overall industry performance.

4 Findings from Scientometric Analysis

Findings from the Scientometric analysis were used to construct a conceptual framework for assessing productivity in I5.0 within the built environment (Posillico et al., 2023; Ullah, 2021). This framework integrates the various identified themes and provides a structured approach to evaluating productivity and performance. Key components of the framework include technological integration, human-technology collaboration, sustainability, and innovation. From the Scientometric analysis, the colour coding represents cluster issues garnered from the investigated papers. The network mapping and the tabulated clusters in the above table are shown in the linked diagram, with their strength and weaknesses also shown in the diagram.

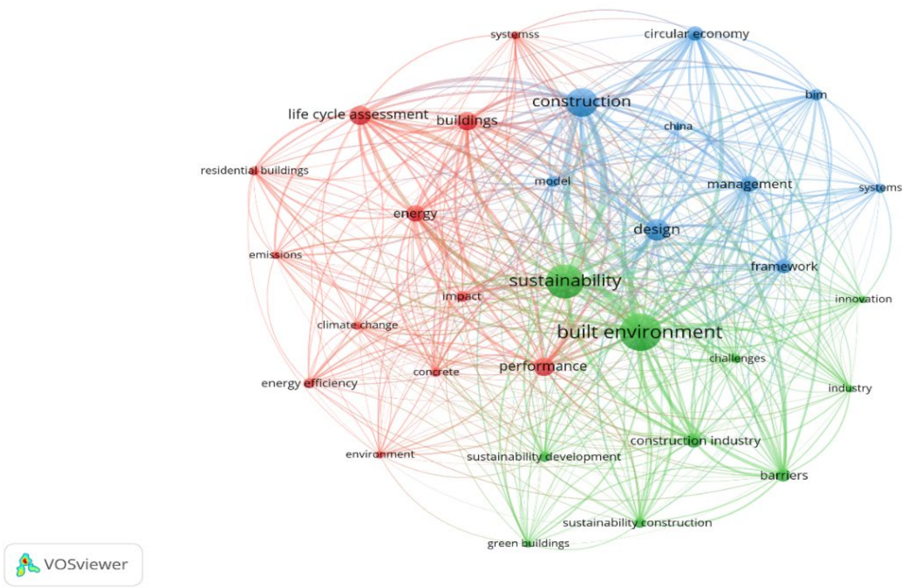

Figure 1. VosViewer output from the investigation of the papers through Scientometric analysis.

Table 1. Tabulated clusters from the VosViewer.

Red Cluster	Green Cluster	Blue Cluster	Yellow Cluster	Purple Cluster
Buildings	Built Environment	Barriers	BIM	Circular Economy
Concrete	Challenges	Construction Industry	Design	Economy
Construction	Cities	Drivers	Framework	
Demolition Waste	Climate Change	Industry	Infrastructure	
Embodied Energy	Energy Efficiency	Innovation	Management	
Emissions	Environment	Strategies	Model	
Energy	Green Buildings	Sustainable Construction	Systems	
Impacts	Health			
Life Cycle Assessment	Impact			
Mechanical Properties	Sustainability			
Performance	Sustainability Development			
Residential Buildings	Urban			
Waste				

5 Towards an improved productivity framework

For a new conceptual economic framework of productivity, this study defaults back to the standard productivity function, the Cobb-Douglas equation, which has been used repeatedly in different subject domains. The Cobb-Douglas productivity function is a widely used mathematical economic model that describes the relationship between inputs (i.e., typically labour and capital) and the output of goods and services. It is expressed as:

$$Y=A\cdot K^{\alpha}\cdot L^{\beta} \qquad (1)$$

Where: (Y) represents the total production (output). (A) represents the total factor productivity (TPF) - a constant representing technology (or a measure of efficiency). (K) represents the capital input. (L) represents the labour input.

Where (alpha) and (beta) are the output elasticities that represent the proportionate change in output resulting from a proportionate shift in capital and labour, respectively, which are constants and sum up to 1. The Cobb-Douglas production function sets the TPF (technology level) as a constant when determining the correlation between input factors and output, which is not consistent with actual production conditions (Wang et al., 2021). Hence, the combination of α and β yields the following: 1). (alpha + beta = 1): The constants return to scale. This indicates that doubling the inputs (labour and capital) will double the output. That is to say that expanding the scale of production will not necessarily increase the output (Y) but yield an increase by the same proportion, and only improving the technical level can improve economic efficiency. 2). (alpha + beta > 1): Increasing returns to scale, suggesting that expanding production inputs by existing technology is beneficial for increasing outputs. 3). (alpha + beta < 1): Decreasing returns to scale, indicating that an increase in production input does not yield commensurate output.

These concepts help economists and businesses understand how changes in labour and capital affect production and overall productivity. While traditional capital typically refers to physical assets like machinery and buildings, the broader definitions recognise the value of intangible assets in modern economies (Crouzet et al., 2022). One of the major forces driving value creation in the era of I5.0 is intangible assets (Diop et al., 2022; Tetiana et al., 2023). Therefore, integrating these into the Cobb-Douglas framework can provide a more comprehensive understanding of productivity. Incorporating intangible assets into the Cobb-Douglas function offers a more thorough understanding of the factors driving productivity in modern economies, especially in the construction industry. This can be done by expanding the traditional model to include these factors as follows:

$$Y=A_o\cdot K^{\alpha}\cdot L^{\beta}\cdot I^{\gamma} \qquad (2)$$

Where: (Ao): represents baseline total productivity factor. (I) represents intangible assets. (gamma) represents the output elasticity of the intangible capitals (I).

Two ways of appreciating the eventual equation to be solved are using econometric and empirical analysis (Wang et al., 2021). However, the solution is still being investigated and will be considered in future research directions. Nonetheless, this would involve collecting quantitative data, which is impossible considering the timeframe for submitting this research output. Hence, from a literature review perspective, it can also be appreciated how certain factors impact the equation. This paper focuses on the latter using Scientometric analysis with the key research question in mind:

"*With new variables like sustainability, CE, and DT diffusion, what will be the markers of productivity and performance in this new reality in the context of industry 5.0*"?

Several intangible assets (variables) drive productivity in the construction industry (Rathnayake et al., 2024). This study will focus on the above-mentioned variables - sustainability, circular economy, and DT diffusion. Therefore, incorporating these variables into the Cobb-Douglas framework, we will have the expanded function:

$$Y=A_0 \cdot K^{\alpha} \cdot L^{\beta} \cdot S^{\gamma} \cdot CE^{\delta} \cdot DT^{\epsilon} \qquad (3)$$

Where: $A = A_0.(S^{\gamma} \cdot CE^{\delta} \cdot DT^{\epsilon})$. $I^{\gamma} = (S^{\gamma} \cdot CE^{\delta} \cdot DT^{\epsilon})$. ($A_o$): Baseline total productivity factor. (S): Sustainability practices. (CE): Circular economy practices. (DT): Digital technology.

Where (alpha, beta, gamma, delta, epsilon): represents output elasticities of capital, labour, sustainability, circular economy, and DT, respectively.

Equation 3 captures the effect of integrating the traditional labour and capital inputs with new variables, also referred to as modern factors (sustainability, CE, and DT), on the total output in the construction industry. The keywords found from the Scientometric analysis could be useful in assessing productivity holistically as appropriate. This function could be initiated by reflecting on the key parameters found from the Scientometric and integrating them within the function for a better result. This enables us to evaluate and appreciate how changes in capital, labour, sustainability practices, CE practices, and DT innovation and diffusion will collectively impact the total output in the construction industry.

6 Conclusions

Most of the data required for developing a new understanding of productivity is available in the field. However, from what is seen, most of the available data requires collection, cleaning, standardisation, and formalisation before it can be translated into a format that will meet current productivity needs. The interpretation of these data is important for productivity to be appreciated from a wider perspective; for example, the time value of money was only appreciated when it was shown clearly that factors impinging on this, like inflation, interest rate, risk, and profitability, disturb the economic worth of the project venture. Similarly, understanding how factors like technological innovation, SDG, and CE issues will impact the way productivity is measured, shifting away from what is known into a credible solution that can be adjusted depending on the variables that are manifesting themselves in the productivity equation. Thus, this will just be the start of such a scenario in understanding the impact of SDG, technological innovation, and CE, for which the current situation of the productivity equation has been transformed. Innovative trends developed from the Scientometric analysis enhance a better understanding of productivity in the BE. Such understanding can trigger policy issues or changes and pinpoint government funding and other private organisational bodies to the factual issues that will underpin productivity and performance soon. The novelty of this approach lies in enhancing the understanding and application of the Cobb-Douglass production function underpinned by Scientometric analysis and its monitoring of productivity gains in the built environment.

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