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Review

The Mediators of the Relationship between Digitalisation and Construction Productivity: A Systematic Literature Review

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Abstract: The construction industry has long been perceived as reluctant to embrace change, and digital transformation is not an exception. The slow adoption rate has been linked to the perceptions of the effectiveness of construction innovations. An implied link exists between digitalisation and productivity improvements. However, such a link is yet associated with ambiguities, suggesting that the influence is not linear. Despite the very low productivity rates achieved in the construction industry, studies on the association between technology adoption and productivity-related benefits and advantages are rare, and this may be a contributing factor to the indecision of construction firms to embrace digitalisation. A systematic literature review enables scholars to disseminate past research efforts in one scholarly resource, in pursuit of new knowledge. Through systematically reviewing the literature, this study identifies, classifies, and critically analyses research efforts, aiming to shed light on the mediators of the relationship between digitalisation and productivity. Overall, sixty articles have been identified, screened, and included in this study. Productivity, in this context, is positively related to digitalization, by promoting more safety and well-being, planning enhancements, collaboration, waste reduction, employee upskilling, design enhancements, communication and knowledge transfer, and accuracy in information management. The findings also reflect the popular use of qualitative methods when studying digitalisation in the construction context, a stance that may be a reflection of a less diverse use of methodological approaches, and presents a call for more quantitative studies, to explore the relationship between digitalisation and productivity. Future research is encouraged to use this extensive review as a foundation for comparable empirical investigations, considering areas of similar interest, to accelerate the adoption of digitalisation.

Keywords: digitalisation; productivity; construction innovation; digital technologies

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1. Introduction

The benefits of digitalisation in construction cover a range of critical areas, addressing environmental objectives [1,2], such as waste reduction [3], safety objectives such as minimising workplace risks [4], management objectives such as controlling time [5], and planning objectives in monitoring construction processes [6]. Moreover, scholarly studies indicate the role of digitalisation in fostering both communication [7], and collaboration [8]. The need for digitalisation is increasing amidst the pressure on the construction industry to address its longstanding challenges. Chiefly, such change is driven by the ability of digitalisation to meet these new targets [9]. Alwan and Ilhan Jones [10] stress this, and shed light on the ways that digitalisation can offer to overcome and contain key construction challenges. However, despite the benefits created by the adoption of innovative technologies [11], there is a lack of consensus among construction firms to heavily invest in digitalisation [12]. The adoption of digitalisation in construction is slow, and this has been linked to the lack of studies that justify the need for digitalisation in construction [12,13]. Despite the demonstrated benefits offered by research, the adoption of digitalisation in construction is still far from achieving a satisfactory rate [14]. One of the key aspects argued

to drive the adoption of such technological innovations, is the substantiated enhancement in productivity [15]. In the construction context, the low uptake of digitalisation is linked to the unawareness of construction professionals of the positive influence of digitalisation in enhancing productivity [16]. Hence, it is logical to state that, illuminating the influence of digitalisation on productivity, may help to achieve a common understanding that favours digitalisation in construction firms.

Despite the global effort to enhance productivity rates of the construction industry in the past 20 years, only a 1% gain in productivity has been recorded [14,17]. Arguably, digitalisation is associated with myriad benefits that can influence better productivity [18], however, limited studies exist to communicate this influence [19], emphasising the need for research to investigate the relationship between digitalisation and productivity. Stojanovska-Georgievska et al. [14] call for investigations to explore the benefits of digitalisation and the relative advantages connected with its adoption on construction productivity. Due to digitalisation's contemporary nature in the construction sector [16,20], studies identifying the benefits and values are limited, and this may be driving less interest for a fundamental transformation [21]. Demirkesen and Tezel [13] call for future studies to address the issue of the unawareness, and ignorance, of construction firms towards acknowledging the benefits associated with digitalisation. Hence, such reasoning motivates the authors to conceptualise the relationship between digitalisation and productivity through the lens of previous research efforts, synthesising this knowledge for a new research objective.

Exploring the correlation between digitalisation and productivity would lead to a theoretical contribution to both research and practice. The adoption of innovations has been a widely researched subject matter, capturing the interest of scholars for decades [22–24]. Chiefly, the element where adopters perceive the innovation as advantageous, has been argued to be a significant predictor for an innovation's diffusion [25]. An application of the diffusion of innovation (DOI) theory to examine the readiness of the construction sector's social system to embrace digital change, reveals the need to better communicate the benefits among social members, rather than solely relying on their technological readiness [26]. Similarly, a critical success factor for the adoption of technologies is directly linked to envisioning a common meaning among the key stakeholders [27], e.g., the key benefits and maturity factors [28]. An understanding, therefore, of the key abilities of innovation, by extending its tangible benefits, may help to justify the low adoption rates [29,30].

Overall, the literature lacks robust explorations that identify the relationship between digitalisation and its influence on productivity. This can be explained by the nonlinear influence of this relationship, being more complex than it is simplistic [31]. Digitalisation is believed to significantly enhance productivity [32]. Such a complex relationship has been illuminated in industries relevant to construction, e.g., manufacturing [33], health [34], and agriculture [35]. Research efforts, however, have been limited, when studying the relationship in the construction setting [17]. Therefore, a research gap exists, to justify a qualitative exploration that can build a theoretical understanding of the mediators that exist between the use of digitalisation and productivity, in a construction context.

Reviewing the literature has been described as effective in detailing digitalisation's benefits and explaining the dynamics behind the influence of digitalisation in construction firms [17]. Moreover, the recognition of the benefits associated with digitalisation may critically influence construction firms' adoption rates and presumed decisions [17]. Hence, there is a critical need for research to explain, and detail, the influence of digitalisation on the productivity of construction, as this may lead to a more favourable adopter perception. Knowing that the purpose of a systematic literature review is to filter and sum the relative available studies in relation to a specific research question, this study utilises this approach to unravel the digitalisation–productivity conundrum, in the construction context. Our understanding of what constitutes the mediators orchestrating the relationship between digitalisation and productivity is lagging, presenting an opportunity to address this knowledge gap. Our qualitative exploratory method, therefore, focuses on examining

recent research efforts, to shed light on the influence of digitalisation on productivity in the construction sector. The following sections present the choice of the method used, followed by the findings and analysis of the included data. The objectives of this study are to:

- Explore the characteristics of previous digitalisation research in the construction context.
- Identify the themes in which digitalisation is excelling at positively influencing productivity.
- Formulate a conceptualization of the identified mediators for empirical investigation.

2. Materials and Methods

A systematic literature review method enables scholars to achieve a higher level of conceptualization, compared to independent studies [36]. Reviewing and analysing past works is a method that allows researchers to systematically approach a subject matter [37]. The use of this method has increased in popularity, due to its transparent and less biased approach in analysing past data towards one dominant research gap [38]. Moreover, such a methodology choice enables the authors to summarise and articulate previous works, while aligning with a new primary aim [39]. Hence, this section details and substantiates the research's methodological process.

2.1. Stage 1: Identifying the Data Source

A systematic review starts with selecting a database of academic contributions [40]. In this paper, the database chosen is Scopus, due to its wide coverage of the literature and global reputation [41]. The search reflects a range of published articles in the last ten years and has led to the inclusion of sixty publications from reputable journals. It is worth noting, that the authors are not trying to convey that older publications hold less merit, but simply stating that this study includes publications from the last ten years, where digitalisation in construction research has gained momentum [42], offering the required comprehensive overview. The cited references are all indexed and can be tracked throughout the database. The reliability of effectively selecting a database to offer scholarly metadata, has been described as vital in review papers [43]. Such a key attribute encourages the choice of Scopus as the main database to explore peer-reviewed publications [41]. Such a choice aligns with Boyle [44], p. 148, who states that Scopus is the "largest single abstract database in the world", offering a broad exposure to multidisciplinary resources [45], and aligning with comparable research studies [46]. Additionally, a manual search of similar search codes with other databases, such as Web of Science and Google Scholar, led to the articles already included in this paper. Figure 1 depicts a PRISMA diagram, that details the four main stages of the process. Overall, the number of articles included is sixty, these have been explored and related to the study's aims and objectives; this number is deemed to be sufficient to pinpoint the key assumptions.

2.2. Stage 2: Rationalising the Search

The search process adopts keywords that are used in recent comparable reviews touching on the same subject [47–50]. The search terms included the keywords "*digitalisation*" OR "*digitalization*" AND "*construction*" OR "*built environment*" OR "*productivity*", which ensured that the authors are reflecting results from both the American and English contexts, and can relate the context of each article to the objectives of this study. Articles included are subject to exclusion if, upon careful screening, they are determined to be (a) based on a non-construction subject, (b) within a ten-year interval, and (c) not realising merit in relating digitalisation to construction productivity, e.g., infer relatable findings that suggest the same. The key merit of systematic literature reviews, compared to other review types, is the inclusion of comparative studies in isolation from the vast available literature and data [51]. To achieve this, an inclusion–exclusion criterion is utilized, to limit the review to the most relevant publications, even if the exclusion supersedes 90% of all articles emerging from the search [52]. Thus, the criteria has been developed in line with the guidelines implied by Krnic Martinic [53], which ensures that, (1) articles included are highly relative

to this study's purpose, i.e., digitalisation in construction, and (2) the results of the study included can be seen as fitting into the overall context of this study, i.e., identifying the relation between the higher use of digitalisation with respect to productivity enhancements.

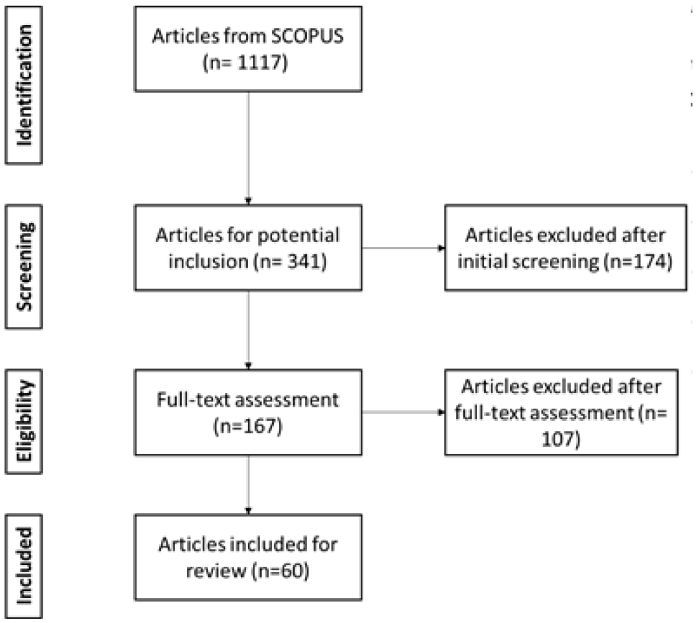

Figure 1. PRISMA diagram.

The first Scopus search was conducted in August 2022, which enabled insights and inclusion of the most recent publications. The condition to include recent studies has been argued as a key characteristic of reviews, to communicate new and contemporary studies to the readers [54]. The first stage included reducing the number of articles from the initial search from 1117 to 341, which was achieved through the metrics offered by Scopus. The tool collectively filters a large number of results, in line with limitation options such as subject area, i.e., construction, document type, i.e., journal paper, language, i.e., English, and publication stage, i.e., final. Such conditioning parameters have been described as highly credible in limiting studies to a number that can then be manually screened in full-text [55]. Moreover, VOS viewer has been utilised to depict the relationships, which is common in comparable digitalisation studies [56] (see Figure 2).

2.3. Stage 3: Classifying the Themes

This paper comprises sixty articles, a number that drove the adoption of a thematic approach, to classify the findings into relative themes. Such analysis choice allows the authors to extract and analyse secondary data from the literature [57]. Data are then classified, in isolation from their original contexts, based on the trends emerging between them [58]. The study adopts the procedure where patterns of repetitive nature are grouped into themes, and then related to the overall aim of the study [59]. Trends and patterns, hence, are indicators of potentially important relationships in systematic reviews [60]. A thematic content analysis extracts meanings from such trends, and is effective when analysing large amounts of secondary data [57]. Such an analysis criterion, therefore, adds consistency to classifying the literature into common themes and genres, concerning the subject area being explored [61]. Thematic analysis is commonly used in systematic reviews, to identify themes based on patterns within the data [62]. Such an approach becomes particularly effective in textually synthesising large quantities of qualitative data [40]. Subsequently, the integration of the findings would act as a summary of the derived meanings, as additional contributions beyond the initial independent intention of these studies. Hence, this study applies a thematic analysis approach, to reveal the

themes that can inform the relationships between the use of digitalisation and productivity enhancements in the construction context.

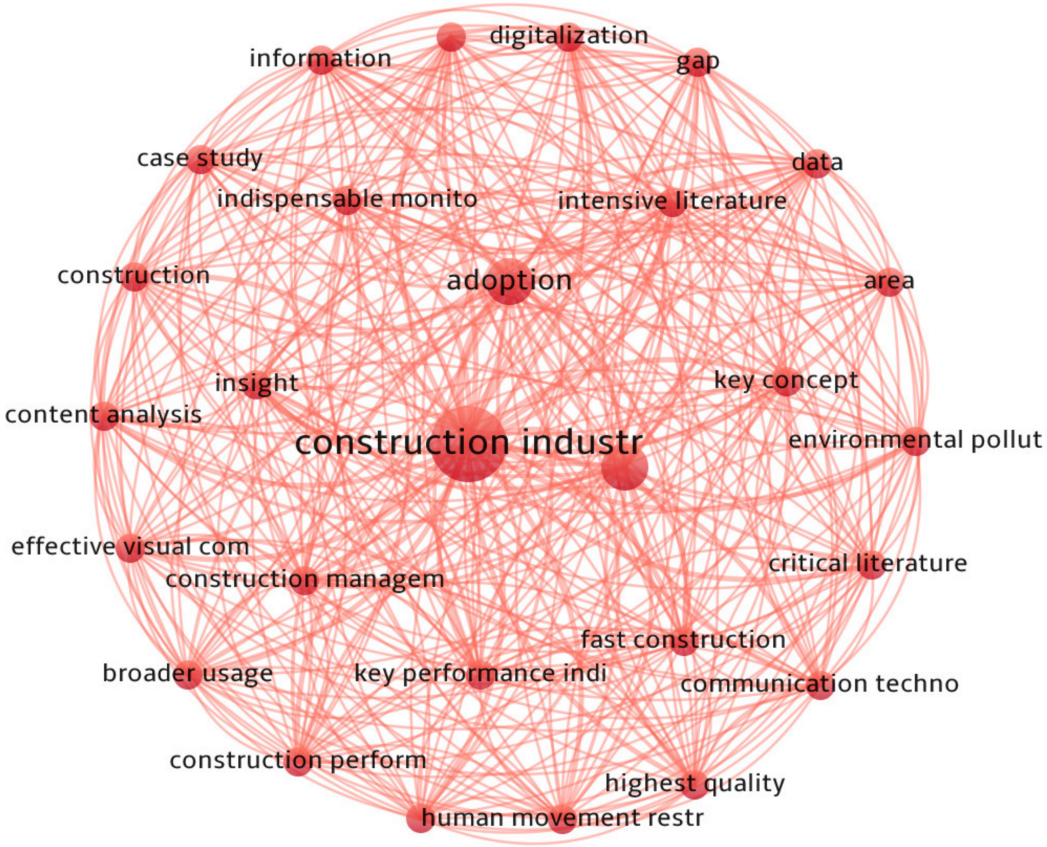

Figure 2. Keyword co-occurrence based on the included articles (60 publications).

3. Results and Discussion

As shown in Figure 3, the number of publications that reflect an interest in digitalisation is increasing over time, as the interest tends to extensively emerge at the start of 2020, sustaining an upward trend ever since. Such attention by academics and researchers is not surprising, as the more publications that cover digitalisation in the construction context, the more we realise the importance and potential of these contemporary advancements [63]. In terms of the distribution of articles among the peer-reviewed journals, Figure 4 shows that most of the research has been published in *Buildings*, *Sustainability*, and *Construction Management and Economics*, all of which are highly rated journals. The articles with respect to their countries, are shown in Figure 5.

Ehwi et al. [64] opined that the majority of publications in the niche of construction innovations utilised a quantitative approach. To verify this in the context of this paper, each of the included papers has been classified into three methods of research use, namely; qualitative, quantitative, and mixed methods, based on their choice. In contrast with previous reviews, the review's findings reveal that 68% of the research methods are qualitative in nature, implying the popularity of these methods when investigating digitalisation in the construction context. Moreover, the findings expose the limited application of theoretical approaches, with only 11% of the included articles utilising theories to explain and interpret their contributions. Articles using theories were limited, and included Lappalainen et al. [65] (who used situational awareness theory); Aghimien, Aigbavboa, Oke, and Aghimien [21] (who applied institutional theory); Hewavitharana et al. [19] (the theory of planned behaviour); Aghimien et al. [66] (the unified theory of technology adoption and use of technology); and Sommarberg and Mäkinen [67] (the theory of disruptive inno-

vation). Hence, we can infer the relatively low interest in recent research efforts to apply theories in their digitalisation context.

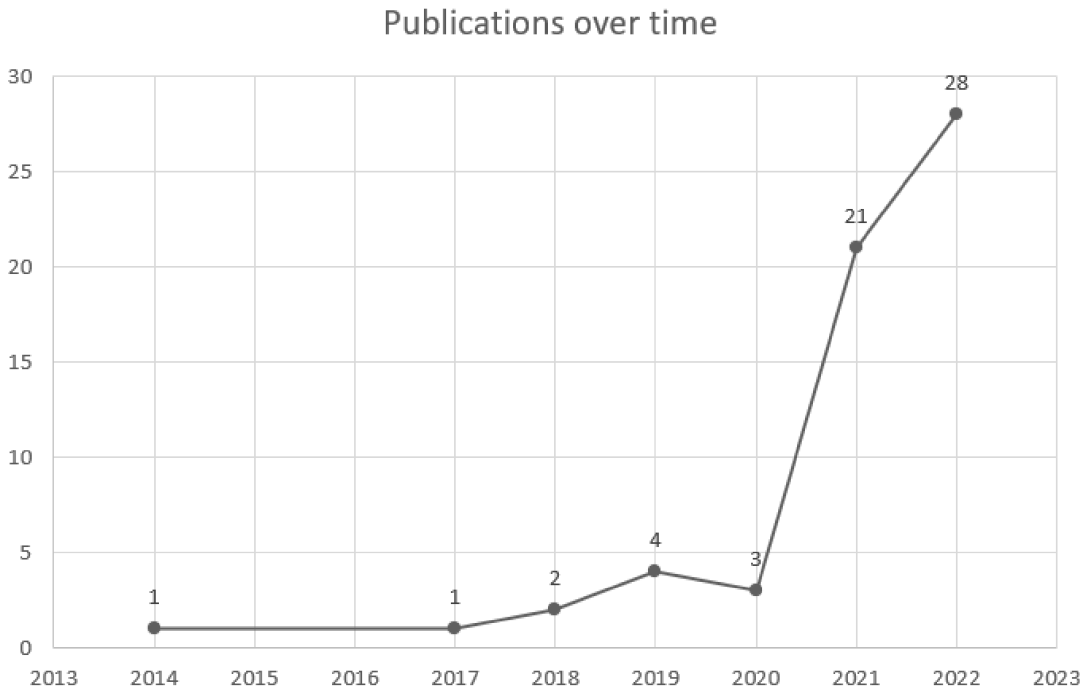

Figure 3. Publication date against article count.

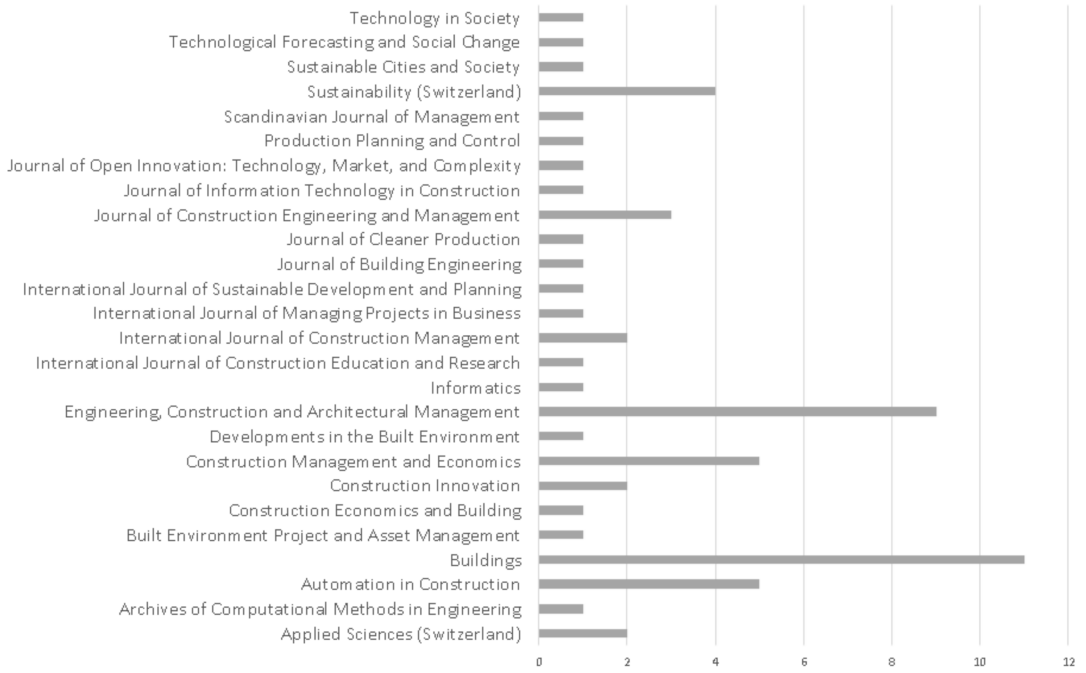

Figure 4. Journal distribution against article count.

This paper follows a systematic literature review process to explore the mediators orchestrating the relationship between digitalisation and productivity. A thematic analysis is subsequently applied, enabling the authors to classify the mediators and promote a range of in-depth discussions. The following subsections include safety and wellbeing, planning enhancements, collaboration, communication, design enhancements, waste reduction, skill development, and error minimisation. The emergence of the themes is not linked to

any pre-determined set of constructs, but are rather inductively identified based on the trends and patterns of the discussions, as opposed to deductive analysis. Such themes, therefore, represent key focus areas to link digitalisation with productivity, where each theme represents a mediator that contributes to this relationship, as shown in Figure 6.

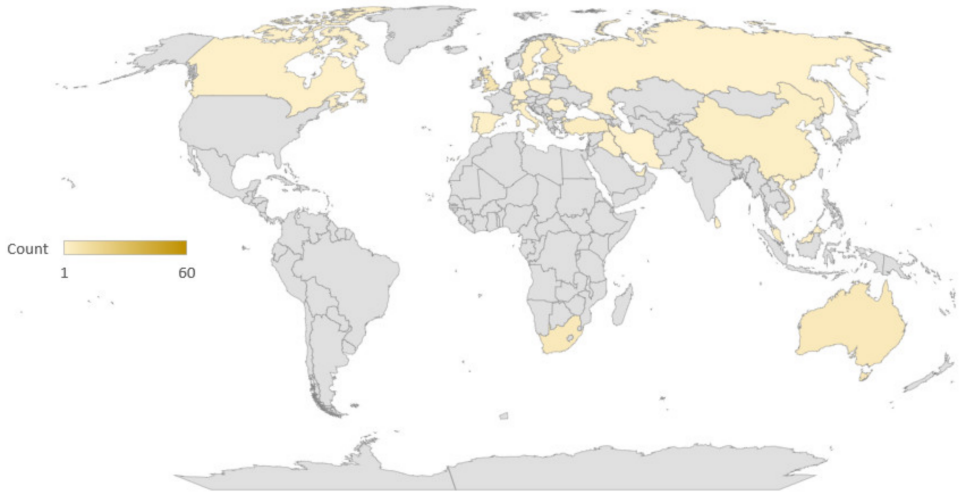

Figure 5. Journal distribution by country.

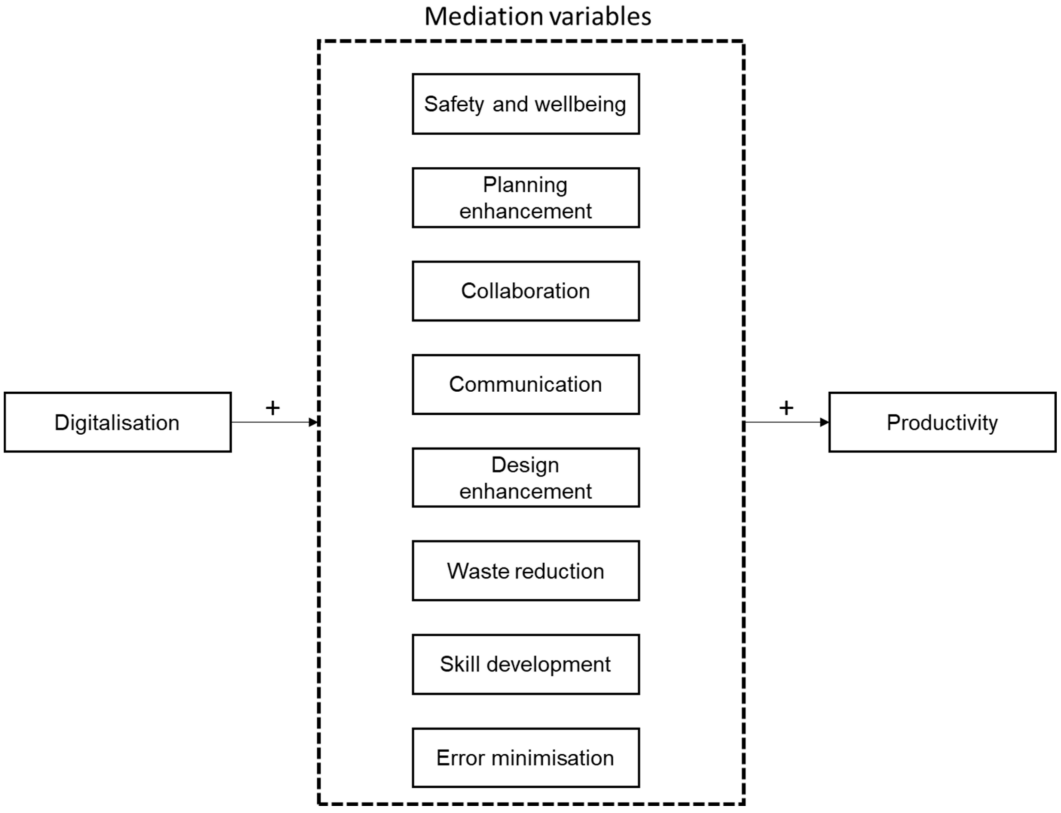

Figure 6. Conceptualisation of the mediators between digitalisation and productivity.

3.1. Safety and Wellbeing

The literature identifies a relationship between the level of safety and well-being of the stakeholders involved in construction projects, with the level of productivity. Orzeł and Wolniak [68] indicate that the comfort and well-being of employees became known during the pandemic, in which the power of using digital tools to sustain an acceptable rate of work was forced into effect by construction organisations. Tentatively, the higher the level

of well-being achieved, the higher the productivity rates. Hallin et al. [69], p. 5, discuss that, 'doing things by hand' does not foster a safe and productive work environment, a stance that is effectively minimised through the use of technologies. Digitalisation, in this context, is linked to reducing the number of accidents on site, as it offers an extended ability of monitoring, and alerts higher management and supervisors upon the emergence of a safety concern [17,70,71]. Another aspect associated with the relationship between digitalisation and construction productivity is the comfort of the stakeholders. Digitalisation makes processes more intelligent, synchronising activities to be more efficient, which meets the goals necessary for stakeholders' comfort and well-being [50]. Hence, a relationship exists between the ability for digitalisation to improve employees' safety and well-being, which are characteristics of a productive environment.

The dangerous environment of the construction industry is due to the naturally associated heavy activities and the need for machinery and equipment with a track record of causing causalities and impacts in a work environment. Digitalisation promotes a less labour-intensive line of work, where hard and risky work conditions are dealt with by systems, having a minimum influence on human lives, thereby, offering a safer workplace that stimulates productivity [18], p. 214. Productivity, in the same context, is also enhanced by the lower dependency on safety supervision and management, due to fewer physical or hazardous activities [69]. The enhanced uptake of digitalisation, moreover, would enable organisations to collect more accurate human data and reflect more informed decisions, relevant to making workplaces and sites safer [72]. Digitalisation's link to productivity enhancements, therefore, can be argued to emerge through the values it offers in fostering employees' safety and well-being.

3.2. Planning Enhancements

The analysis of the selected articles reflects a relationship between digitalisation and planning enhancements, informing a potential mediator effect on productivity. Liu et al. [73] discussed that this relationship exists amidst the complex nature of construction tasks, as digitalisation tends to shape networks that can support effective and efficient planning. Effective planning means that fewer tasks would be discarded, as all activities are tracked, due to this extended ability of digitalisation [74–76]. Another influence on planning in construction, is the ability of digitalisation to offer a database of information that can reflect precise planning decisions [62,65]. This means that decision-makers can anticipate the events that cause disruption much more easily, in contrast to traditional situations, due to the clarity associated with the availability and reach of the information [77,78]. Empirically, Zheng et al. [79] indicate the effectiveness of digitalisation in achieving critical time savings, this is proposed to be due to effective planning achieving, alone, a staggering rate of over three months of time reduction. Similarly, Barkokebas et al. [12] discuss a case study, in which a 47% time reduction in tasks is exclusively linked to digitalisation. Hence, we can conclude that planning is another potential key mediator shaping the positive relationship between digitalisation and productivity.

3.3. Facilitating Collaboration

Facilitating collaboration between construction project stakeholders is another aspect that can highlight the relationship between digitalisation and productivity. The use of digitalisation is said to communicate transparent and traceable information to parties involved in a construction project, and by doing so, yield better collaboration [47]. The role that digitalisation can play in nurturing collaboration among construction groups can be hardly limited to one aspect, due to the wide power of technologies to better connect parties involved [14,17,80]. Technically, collaboration is enhanced through exploiting digital data and the ease of sharing the said data across several platforms, with minimum redundancy or information loss [49]. Empirically, Lappalainen et al. [65] studied a case in which digitalisation has proven effective in bridging the gap between multiple stakeholders at different levels, at an event that fostered collaboration and succeeded in addressing clients'

needs. The influence of digitalisation in promoting collaboration could be linked to clarity, ease of sharing, and accuracy, all of which are key determinants that foster connectedness and increase accountability. Aghimien et al. [81] indicate the importance of rolling out such benefits initially, and at an early stage, to ensure these capabilities are effectively harvested. Another dimension digitalisation conveys, in addition to the above, is trust among parties and peers. Scholarly research reiterates the stance that digitalisation is associated with an enhanced level of trust, a key aspect that supports effective collaboration [82,83]. However, despite the evidence suggesting collaboration is critically supported by a higher level of digitalisation, research is still limited in providing a wider empirical proof of this relationship [75,84], however, the more digitalisation that is effectively embedded in a construction organisation, the more collaboration is tentatively sensed, and in turn, the higher the productivity.

3.4. Waste Reduction

The relationship between waste reduction and productivity has transpired as a theme in the collected articles. Li et al. [47] discuss that a focus on waste reduction reflects a movement towards a smarter built environment, linking such attributes with the characteristics of smart cities. Overall, this theme aims to unravel the relationship between waste reduction and productivity enhancements. The literature has explained this relationship to the benefits associated with waste reduction, beyond the environmental aspects, where Aghimien et al. [66] underline that the lower the waste, the more the efficiency. This means that the characteristic of a productive environment is the existence of an effective waste management system, that substantiates and measures waste in construction [85]. Similarly, Säynäjoki et al. [86] indicated the influence of waste management on driving cooperation and motivating reforms in existing business models. Digitalisation, therefore, may be described as a pioneering innovation towards more waste reduction [87], where it extends the industry's ability to repair its bad reputation, regarding its lag in sustainability [88], which in turn, motivates more productivity [11]. Hence, in this subsection, we aimed to reveal the linkage between reducing waste and productivity, a relationship that is well-defined in the existing literature.

3.5. Drive Employee Skill Development

The employee skill development theme transpires to inform us of the connection between digitalisation and productivity. Employee skill development is represented by the pressure imposed on employees to develop and thrive, in order to embrace the changing environment and respond to the competitive nature of their roles. A competitive drive is described as an advantage, as it encourages skill improvement, and subsequently, drives more efficiency in a job [89]. The emergence of digitalisation, therefore, could be looked at through two different lenses, one being a threat to current roles [18], and another being a potential opportunity that drives development [9]. The former may be explained by the capabilities of digitalisation to reduce the number of workers on site [77], while the latter perceives digitalisation as a potential that would ensure employees are radically developing their skills [90–92], where future recruitment would then focus on the employment of competences in the workplace [69]. Digitalisation, in this context, is argued to motivate the upskilling of employees, through seeking information and knowledge, as an attempt to adapt to a new reality and sustain their roles. This stance will create a more robust social system of employees within firms, in terms of skills and knowledge, motivated by the fear of job loss, but has a significant influence on enhancing productivity, through skill intensity [93].

An adequate fostering of digitalisation, however, calls for measures to ensure the correct flow of information upon employee development. The literature underlines the need for firms to support their employees in this transformation, through continuous webinars and educational materials, which would facilitate awareness and knowledge among peers [66,78]. Similarly, Nikmehr et al. [11] emphasised the importance of restructuring

and firm modifications, that would facilitate digitalisation among employees. Jacobsson and Linderoth [94] discussed that, among the champions fostering the drive for digitalisation are new graduate students. The critical role of new graduates in communicating positive trust and confidence in digitalisation is argued to be a driver for other peers in the social system. Arguably, the nature of digitalisation dictates an interplay between a spectrum of disciplines, where a strategy may be needed to build and harmonise employees' capabilities [67]. The relationship between the firm and its employees has a complex interaction, with interchangeable influences, calling for an adequate focus on the internal processes to support the external change, and not vice versa, through effective leadership and management [84]. A transformation, indeed, may be perceived as challenging [13]. Productivity enhancements, however, may act as a sufficient purpose, that can foster and drive employee development in the construction industry [17]. Hence, digitalisation has been argued to drive and encourage employee development, which is a key element that influences productivity.

3.6. Design Enhancements

The enhancements in design to the overall construction productivity, are another feature facilitated by digitalisation. Firstly, Orzeł and Wolniak [68] studied the extended potential offered by digitalization, to promote designers' remote working, a potential that meant higher productivity, compared to the traditionally limited co-working workplaces. Digitalisation enables companies to track real-time design progresses and make informed managerial decisions accordingly [65,95]. Similarly, Alwan and Ilhan Jones [10] and Nikmehr et al. [11], described how decisions that lead to reducing carbon in the design phase, are directly linked to the values offered by digitalisation. Productivity, herewith, is sensed in the design phase by the ease of data transfer within key models [96], promoting critical interactions with designers and other parties [97]. This aligns with what has been underlined by McNamara and Sepasgozar [75], on the power of digitalisation to enable fewer clashes within designs and with dealing with complex data, all of which can be linked back to the influence of digitalisation on productivity.

Productivity, as apparent in studies, is positively related to the use of digitalisation. The benefits of digitalisation through productivity extend to reflect myriad benefits. For instance, the influence of design enhancements due to digitalisation has been linked to up to 21% of savings [14]. Such usage is not limited to a single software, digitalisation is rather enhancing the design phase, with improvements that range to cover digital photogrammetry [98], building information modelling (BIM) [14], geographic information systems (GIS) [49], and visualisation [97]. The adoption of such a variety of digital tools is where the merit lies. However, digitalisation is argued to still be far from being widely comprehended by design companies [84]. Enhancements in the key design phase have traced and well-recorded benefits on productivity in the subsequent phases, hence, pinpointing the role of digitalisation in indirectly influencing productivity through this mediation variable.

3.7. Communication and Knowledge Transfer

A key characteristic of digitalization, is the ability to drive better communication and facilitate knowledge transfer, all of which are key aspects that ensure adequate productivity. Säynäjoki et al. [86] touch on this, by describing that the attribute of a digitalised business is the distinguished distribution of data. Data transfer is argued to be minimal in the construction context [16,99]. The use of digitalisation, nevertheless, is directly linked to critical enhancements to communication, as the ease of work offered due to this, has influenced greater comfort for construction employees [68]. The higher effectiveness of communication and knowledge transfer due to the use of digitalization, can be explained by the technical capabilities of the adopted tools, proving competent in capturing data [70], accurately reporting project issues [74], and securely storing delicate information [9,100]. For instance, Ayat et al. [77], p. 667, used the word "localisation", to describe the ability of digitalisation to pinpoint communicational benefits. Communication and knowledge transfer, therefore,

extends the managerial abilities to be well briefed on all aspects influencing a productive environment, and accordingly, allowing informed actions [72,93].

The transformation towards digitalization, means a transition from a workplace that is centred around documents, to one more focused on information [101]. This theme reflects the literature's contributions and implications, by reiterating the novelty associated with the higher use of digitalisation on productivity through communication. In addition, to the above values and impacts on communication and knowledge transfer, Barkokebas et al. [12] proposed the ability to exploit the ease of reaching data of more value, by minimising rework and meeting client's requirements, another determinant that links digitalisation with productivity. Therefore, we can acknowledge that the bridge between this theme and the level of digitalisation is the methodical interaction among stakeholders and the ease of exchanging and tracing credible data [87]. Gharouni Jafari et al.'s (2021) statement corroborates that of Ozturk [102], by addressing the key phases of dealing with data in a digitalised environment, reporting these as capturing data, storage, and sharing of information. It is logical to state that digitalisation accumulates knowledge [82], increases communication [75], and motivates knowledge transfer [17]. Hence, digitalisation drives better communication and knowledge transfer, and in turn, drives productivity enhancements.

3.8. Accuracy and Error Minimisation

The ability to ensure accurate information and minimal recorded errors within a workplace are key for adequate productivity. Digitalisation, albeit broader in the sense of peculiarity, has been extensively discussed within the studies, as the main cause for an accurate flow of information [98,103,104]. For instance, Shahzad et al. [70] explained how digitalisation extended the capabilities of information management, which led to the retrieval of key behavioural information and the application of the same, in virtual means. To understand how digitalisation influences productivity, it is imperative to understand the challenges imposed by the inaccurate flow of information. The challenges elucidated from the publications extracted for this study, include the problematic nature of accurately diagnosing the factors that impact productivity, and making decisions to enhance productivity, uninformed by a higher involvement of humans in the process [72]. Accuracy, in this sense, is the minimal involvement of the human factor, that is considerably linked to errors and inaccurate data transfer [69]. Bazán et al. [96] indicated that digitalisation's existence yielded a consensus among entities on the minimal concerns that would influence the accuracy of data, reflecting the confidence such innovation can impose on construction stakeholders. The assurance that data is being transmitted accurately, through effective reporting, 3D visual potential, and information tracing [82], can all represent the effectiveness of digitalisation in enhancing productivity in the construction context. Thus, minimising errors and reaching broader accuracy can be seen as a mediator between productivity enhancements and the higher use of digitalisation.

4. Conclusions and Further Trends

This study aimed to disentangle the means which may be undermining the uptake of digitalisation in construction organisations, due to the difficulty of achieving common nomenclature when evaluating its effectiveness. The key assumption in this study, is that existing research efforts are of an "out of sight" nature, inhibiting a clear and direct relation to informing decision-makers on the values of digitalisation concerning productivity. The study addressed transpiring concerns and reviewed significant recent publications, to pave the way for an empirical investigation.

From the critical analysis of sixty articles, the findings suggest eight themes that are conceptually correlated, and deemed critically relevant, to be placed as mediators of the influence of digitalisation on construction productivity. These are, safety and well-being, planning enhancement, collaboration, communication, design enhancement, waste reduction, skill development, and error minimisation. Each of the identified mediators has a track

record in enhancing productivity, as substantiated in the literature. Our findings suggest that the use of qualitative methods of research dominates the included publications. A stance that may delimit a diverse use of methods and may require considering quantitative means to capture and investigate digital adoption. Moreover, the findings inform on the nature of the circular narrative of the emerging themes relative to digitalisation, implying a regenerative stance influencing productivity in the construction sector.

This review concludes that it is assumed that the emerging interest in digitalisation will largely shape construction management research in the near future. Such interest is evident in the increasing number of publications meant to address the role of digitalisation in the construction industry. Therefore, future research efforts must focus on the effectiveness and adoption of digitalisation in the construction context, as these means are proving to have a considerable ability to address the construction challenges that have, for decades, bedevilled both practice and research. Future studies in the forte of construction digitalisation are expected to place this exploratory review as a foundation, where the provided mediators are to be empirically validated and tested in terms of influence and significance, this includes verifying these groupings, identifying the measuring determinants, and clustering the themes into larger groupings, through exploratory and confirmatory analysis. Moreover, future studies are encouraged to explore the flow of other construction innovations in relation to their adoption in a complex social system like the construction industry, areas of interest may include 3D printing, offsite construction, and other innovations that are effectively benefiting from the broader uptake of digital innovations.

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