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Computerized systems in the early-stage real estate development: a systematic literature review in the context of Construction 4.0

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Abstract:
Understanding how digital technologies support decision-making throughout the lifecycle of civil engineering projects has become increasingly relevant in the context of Construction 4.0. However, existing studies have predominantly focused on construction execution, while the early stages of project development remain less explored. This study presents a systematic literature review aimed at identifying and structuring the digital technologies and computerised systems applied to the early-stage real estate development within civil engineering projects. The review followed the PRISMA protocol and analysed publications retrieved from major scientific databases. After the screening process, 50 studies published between 2016 and 2025 were selected for bibliometric and qualitative analysis. The results indicate a significant growth in research after 2020 and highlight the increasing role of technologies such as Building Information Modelling (BIM), big data analytics, machine learning, and digital twins in supporting market analysis, feasibility assessment, and early-stage decision-making. Despite these advances, the literature still reveals limited integration of digital systems across the project lifecycle. The study synthesises current knowledge on digital transformation in construction project development and identifies research gaps for future research.

Keywords:
construction 4.0; real estate development; computerised systems; digital technologies; systematic literature review

1. Introduction

The real estate sector plays a fundamental role in economic development, influencing urban growth, infrastructure expansion, and investment dynamics in several countries. In this context, the development of real estate ventures involves complex processes integrating technical, legal, financial, and market-related activities [1-5].

Real estate development can be understood as the formalisation and technical, legal, and commercial structuring of a building project. This process integrates knowledge from engineering, architecture, and law to enable the development of real estate ventures in a legal, organised, and economically sustainable manner [6-9]. Technically, real estate development can be considered a broader macroprocess in which a natural or legal person assumes responsibility for conceiving, structuring, and enabling the implementation of a real estate project, from land prospecting to the delivery of completed units to the market [10-12].

Within this structure, a macroprocess represents a set of processes and/or subprocesses grouped by common objectives [103]. Therefore, real estate development comprises three main processes: the early-stage real estate development, the production process, and the post-construction process, each structured into subprocesses and specific activities [13,14]. Figure 1 illustrates the real estate development macroprocess, presenting its processes, subprocesses and activities.

As shown in Fig. 1, the real estate development is described as a macroprocess that comprises three main processes. Early-stage real estate development comprises the project's initial phase and includes subprocesses such as market research and product definition, feasibility analysis, land acquisition, legal approvals, and project launch. The production process refers to construction execution and internal logistics related to project execution. Finally, the post-construction process includes conclusion and property delivery, as well as technical assistance and warranties provided after delivery to the end user.

The duration of these subprocesses may vary according to project characteristics, regulatory requirements, and market conditions. For instance, feasibility analysis and legal approvals may take from several months to years, while production subprocesses typically extend for 18 to 24 months, and post-construction subprocesses up to 5 years, illustrating the long-term and multidisciplinary nature of real estate projects.

Within the macroprocess presented in Fig. 1, the early-stage real estate development corresponds to the subprocesses that precede construction and structure the project from technical, legal, and market perspectives. These subprocesses support

decisions related to product definition, financial feasibility, and regulatory approval [18-23]. Figure 2 details the subprocesses associated with early-stage real estate development and their estimated timelines.

As illustrated in Fig. 2, the early-stage real estate development comprises five main subprocesses: market research and product definition, feasibility analysis, land acquisition, legal approvals, and project launch. These subprocesses are sequentially organised and involve technical and managerial activities required to structure the venture before construction begins [24-27]. The execution of these subprocesses presents several operational and strategic challenges. Market research and product definition depend on reliable demand data and accurate forecasts, while feasibility analysis requires integrating financial, legal, and technical information [28-30].

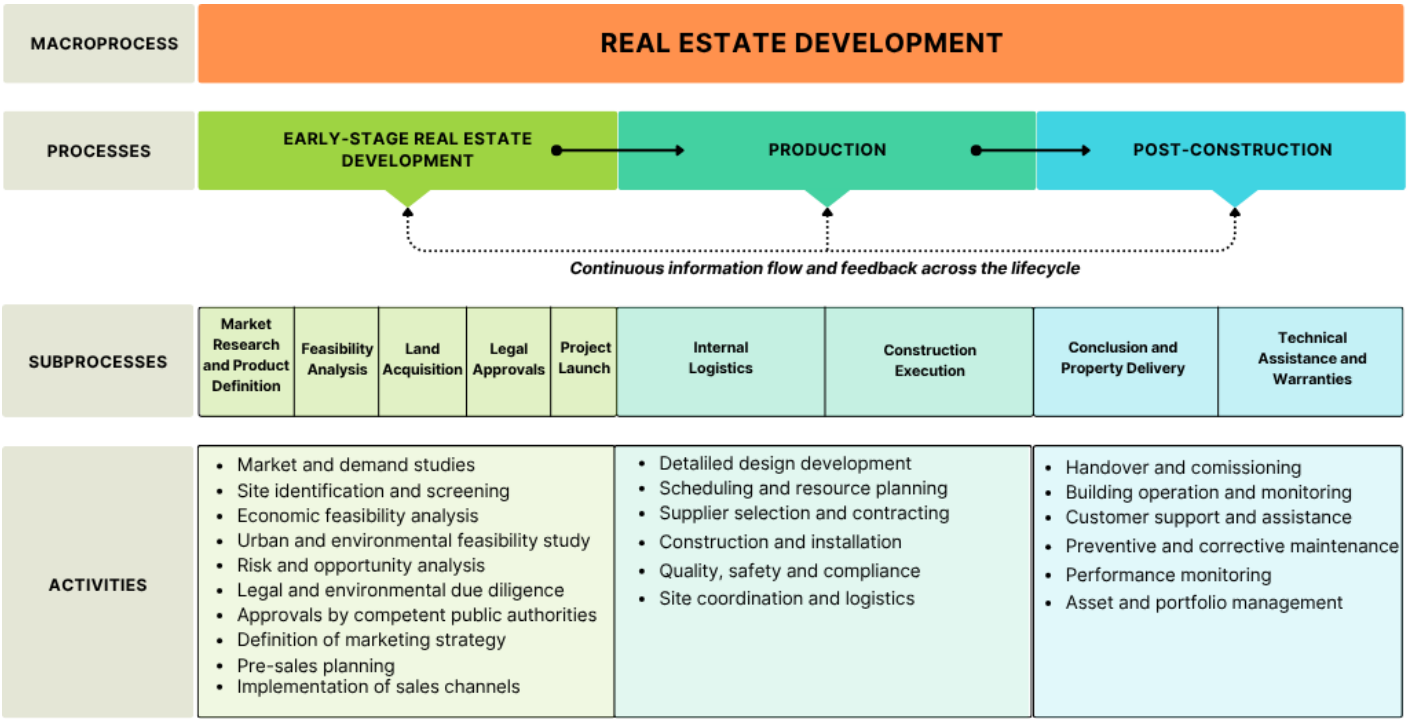

Fig. 1. Real estate development macroprocess. Source: based on [15-17]

Fig. 2. Subprocesses associated with early-stage real estate development and its respective timelines. Source: based on [15-17]

Similarly, land acquisition may involve complex negotiations and legal verification procedures, and legal approvals often depend on lengthy regulatory processes. Project launch also requires coordination between marketing, sales, and technical teams. These challenges frequently lead to delays, fragmented information flows, and uncertainties in strategic decision-making throughout the early-stage real estate development [31-34].

In this context, the adoption of computerised systems and digital technologies has become increasingly relevant for supporting information management and decision-making within the real estate development macroprocess [35-37]. These technologies can improve data integration, facilitate communication among stakeholders, and support the management of complex activities involved in structuring real estate ventures [38-40].

Within this scenario, the concept of Construction 4.0 has emerged as an important paradigm for the digital transformation of the architecture, engineering, construction, and operation (AECO) sector [41-43]. Construction 4.0 refers to technological transformations applied to the construction industry, emphasising new processes, materials, and market dynamics aimed at improving efficiency, innovation, and integration throughout the building lifecycle [44-45].

Similar to Industry 4.0, Construction 4.0 is structured around nine technological pillars: big data, cybersecurity, cloud computing, system integration, Internet of Things (IoT), additive manufacturing, autonomous robots, augmented reality, and simulation [46-47]. Although recent literature has begun to treat artificial intelligence (AI) as an additional pillar of Construction 4.0, this study considers AI a transversal enabling technology that enhances several pillars, particularly Big Data, simulations, system integration, robotics, and IoT.

Despite the growing discussion of these technologies, most studies focus on the production phase of construction projects, particularly activities related to execution, automation, and digital fabrication. Comparatively less attention has been given to early-stage real estate development, especially subprocesses

related to market analysis, feasibility assessment, land acquisition, legal approvals, and project launch. Consequently, there is still limited understanding of how computerised systems and digital technologies associated with Construction 4.0 support decision-making and information management in these subprocesses [48-50].

Therefore, this study conducts a systematic literature review (SLR) to identify, classify, and analyse how computerised systems and digital technologies associated with Construction 4.0 are applied within the subprocesses of the early-stage real estate development. By synthesising the existing literature, the study structures the current state of knowledge on the topic and identifies research gaps that may guide future investigations on the digital transformation of early-stage real estate ventures.

2. Materials and methods

This SLR investigated the use of digital technologies and computerised systems in the early-stage real estate development of developer companies. The review followed a PRISMA-based protocol to ensure methodological rigour, transparency, and replicability through the stages of identification, screening, data extraction, and synthesis [51].

The research scope was defined using the PICo strategy, which supported the identification of the Population, Interest, and Context and the formulation of the research questions [52]. The Population refers to the early-stage real estate development, the Interest to digital technologies and computerised systems, and the Context to developer companies within the Construction 4.0 framework. Accordingly, two research questions guided the review: (i) how digital technologies and computerised systems are applied by developer companies in the early-stage real estate development under Construction 4.0, and (ii) what strategic role these technologies play in this process.

Based on the PICo criteria, search terms related to real estate development, technology, and Construction 4.0 were combined using Boolean operators to form the search string: ("real estate" OR "real estate development") AND technology AND ("construction 4.0" OR "industry 4.0 in construction" OR "construction digitalisation").

The search was conducted in ScienceDirect, Web of Science, Scopus, IEEE Xplore, and Emerald Insight. These international, multidisciplinary databases were selected for their broad coverage of peer-reviewed publications in engineering, construction, information technology, and management, thereby ensuring the reliability and scientific quality of the retrieved studies. Study selection followed PRISMA guidelines through title and abstract screening using the predefined inclusion and exclusion criteria presented in Table 1.

Table 1. Inclusion and Exclusion Criteria defined in the SLR protocol

Criterion	Criterion Type	Code	Description
Topic Relevance	Inclusion	IC1	Studies addressing the use of digital technologies and computerised systems in the early-stage real estate development within the Construction 4.0 context.
Study Type	Inclusion	IC2	Qualitative studies (case studies, interviews, focus groups), quantitative studies (experimental, observational, surveys/questionnaires), and descriptive studies.
Publication Period	Inclusion	IC3	Articles published between 2016 and 2025, considering the recent technological acceleration in civil construction.
Publication Language	Inclusion	IC4	Studies published in English, Spanish, or Portuguese.
Lack of Topic Relevance	Exclusion	EC1	Studies that do not address digital technologies or computerised systems in real estate development or are outside the Construction 4.0 context.
Irrelevant Study Type	Exclusion	EC2	Exclusion of simple literature reviews, opinion articles, editorial comments, or studies without empirical data.
Duplicate Publications	Exclusion	EC3	Exclusion of repeated studies in the searches to avoid bias and redundancy.
Publication Period	Exclusion	EC4	Articles published before 2016.
Publication Language	Exclusion	EC5	Studies published in languages other than English, Spanish, or Portuguese.

In the identification phase, software filters were applied to remove duplicate records (EC3). During the selection phase, title and abstract screening excluded studies not focused on technologies and computerised systems in real estate development (EC1). Subsequently, full-text analysis excluded secondary studies, such as literature reviews (EC2), and articles that were unavailable for complete assessment.

The remaining studies were included in both the quantitative and qualitative synthesis stages, enabling the identification of technological trends, application patterns, interactions among digital technologies, and research gaps in early-stage real estate development within the Construction 4.0 context.

Overall, the database search yielded 527 records: 271 from IEEE Xplore, 189 from Scopus, 36 from Emerald Insight, 29 from ScienceDirect, and 2 from Web of Science. After removing 21 duplicates, 506 records were screened, of which 420 were excluded based on titles, keywords, abstracts, and eligibility criteria. This resulted in 86 records assessed for eligibility, of which 36 were excluded after full-text analysis, leading to a final sample of 50 studies included in the SLR. Figure 3 presents the PRISMA flowchart of the review process.

Following the eligibility assessment, the selected studies were analytically categorized according to their predominant research characteristics and thematic focus areas, including BIM and digital process integration, artificial intelligence and automation, digital twins and immersive environments, blockchain technologies, Industry 4.0 applications, organizational digital maturity, barriers to digital transformation, public policies, sustainability-related digitalization approaches, and other emerging digital technologies applied to early-stage real estate development. This categorisation supported the comparative and analytical synthesis of the literature beyond descriptive classification.

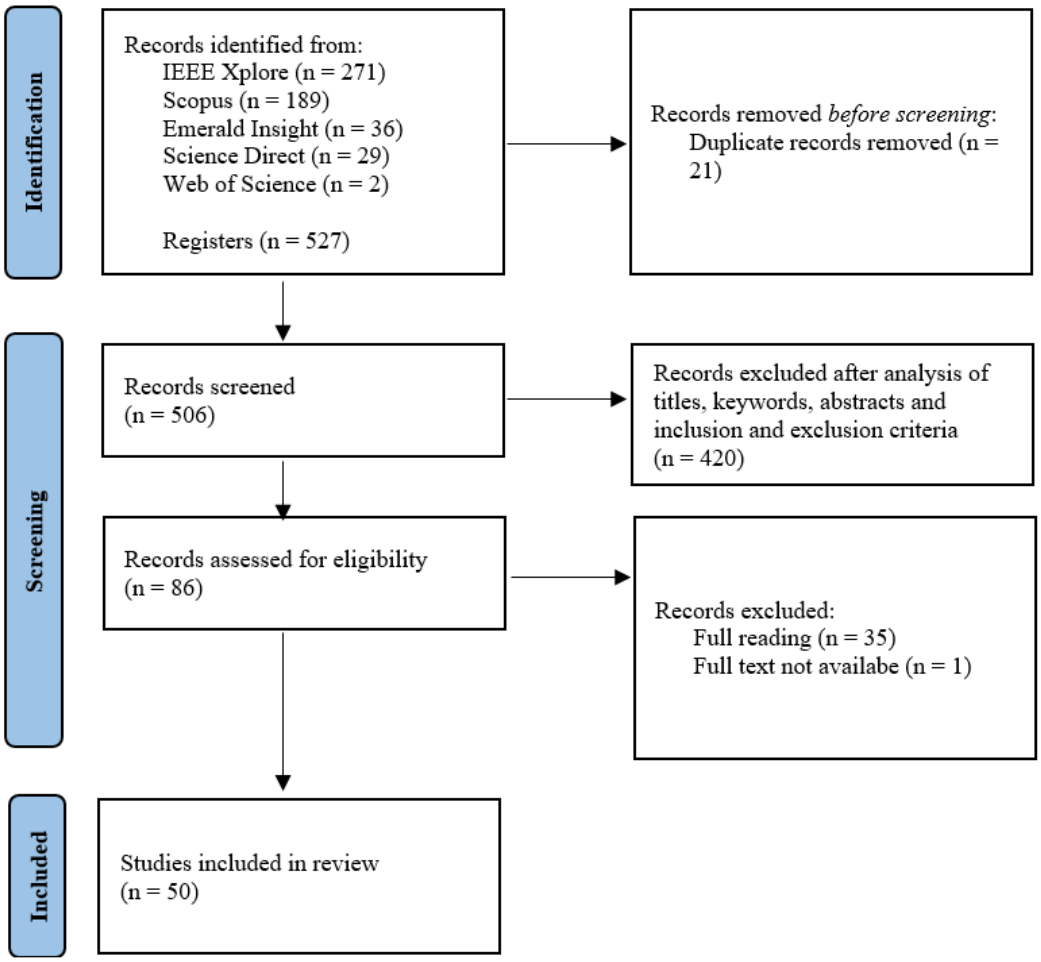

Fig. 3. PRISMA flowchart summarising the selection of articles for the SLR. Source: based on [51]

In addition, some limitations of this review should be acknowledged. First, the study was restricted to publications indexed in five international databases and limited to articles published between 2016 and 2025 in English, Portuguese, and Spanish. Second, due to the emerging, interdisciplinary nature of real estate development and Construction 4.0, some studies on early-stage real estate development may not explicitly use standardised terminology, which may have limited retrieval. Moreover, part of the identified literature overlaps with broader construction management and production process digitalisation studies, reflecting the current concentration of Construction 4.0 research on construction execution rather than early-stage real estate development.

3. Results

The results of the SLR are presented in two complementary components. The first corresponds to a quantitative bibliometric analysis of the selected studies, while the second consists of a qualitative synthesis of the technological approaches and strategic roles identified in the literature. Together, these analyses provide a structured overview of the evolution, thematic focus, and technological trends related to digital technologies and computerised systems in the early-stage real estate development within the Construction 4.0 context.

3.1. Quantitative results

The final portfolio of the Systematic Literature Review (SLR), composed of 50 articles selected according to the defined methodological protocol, is summarised in Table 2. The studies were grouped according to common research characteristics aligned with the research questions of this study, allowing a thematic interpretation of the literature. The synthesis considered the technological focus, the predominant research methods, and the contribution of each study to understanding (i) how digital technologies and computerised systems have been applied within Construction 4.0 and (ii) the strategic role of these technologies in the early-stage real estate development. For each thematic group, the references and the country where the research was conducted are presented.

Overall, the identified thematic categories demonstrate that the current Construction 4.0 literature is strongly concentrated on technologies associated with information integration, automation, and production optimization. However, comparatively fewer studies explicitly address the strategic and decision-oriented subprocesses of early-stage real estate development, such as market research and product definition, feasibility analysis, and land acquisition, thereby reinforcing an important research gap in the digitalisation of real estate development.

The reviewed publications cover the period between 2016 and 2025, corresponding to the consolidation phase of concepts associated with Industry 4.0 and Construction 4.0. Regarding the geographical distribution of the studies, India presented the highest number of publications (nine articles), representing 18% of the portfolio. China, Nigeria, and Malaysia each contributed five publications (10%). The predominance of studies conducted in emerging economies may reflect the growing pressure for productivity gains, urban expansion, and technological modernisation in rapidly developing construction markets.

Table 2. Synthesis of the final portfolio of the SLR

Common research characteristics	Reference(s)	Country(ies)
BIM and digital process integration	[53-61]	Malaysia; Canada; New Zealand; United Kingdom; Slovakia; Norway; Pakistan; India; Kenya
AI, Machine Learning, and automation for decision support and performance optimization	[62-68]	Vietnam; International collaboration; Nigeria; South Africa; Malaysia; India
Digital Twins, metaverse, and immersive environments applied to the project lifecycle	[69-73]	International collaboration; New Zealand; United States; Germany; India
Blockchain and distributed technologies	[74-77]	International collaboration; China; Nigeria
Robotics and 3D printing (Industry 4.0)	[78-80]	China; Malaysia; Nigeria
Big Data, digital frameworks, and organisational technological maturity	[81-86]	United Kingdom; Dominican Republic; China; International collaboration; Australia; Malaysia
Digitalisation in SMEs and scalable solutions to expand technology adoption	[87]	United Kingdom
Barriers, risks, and critical factors for digitalisation and continuity of digital transformation	[88-96]	South Africa; India; Nigeria; Saudi Arabia; Malaysia
Public policies and institutional drivers of digital transformation	[97-98]	China
Sustainability, Lean Construction, and operational efficiency associated with digitalisation	[99-100]	United States; Russia
AR/VR in the real estate market	[101]	India
Integrated Digital Delivery (IDD)	[102]	Singapore

Other regions, including South Africa, the United Kingdom, and the United States, also presented relevant contributions. Studies categorised as "International collaboration" correspond to research conducted by authors from multiple countries. Based on the origin of the publications, a T-matrix was developed relating the studies according to country, journal of publication, and research methods adopted, as presented in Table 3.

The information presented in Table 3 indicates a predominance of studies using the survey method, representing 15 publications (30% of the sample). This method appears most frequently in studies conducted in Malaysia and in international collaborative research. The modelling approach was the second-most-used method, with 13 publications (26%). The predominance of survey and modelling approaches suggests that the field is still evolving toward exploratory and technology-oriented investigations, while fewer studies provide empirical evidence regarding long-term implementation outcomes in real estate development organisations.

The articles included in the SLR were distributed across 35 academic journals, demonstrating the multidisciplinary nature of research on digital technologies and Construction 4.0 in the construction sector. Figure 4 illustrates the geographical distribution of the studies and the research methods employed.

Table 3. T-Matrix relating countries, journals, and research methods

Research method		Survey	Case Study	Literature Review	Model	Mixed / Other
Journal	Ain Shams Engineering Journal	0	0	0	1	0
	Asia Pacific Management Review	0	0	1	0	0
	Automation in Construction	1	0	0	1	1
	Buildings	2	0	1	0	1
	Business Process Management Journal	0	0	0	0	1
	Computers in Industry	0	0	0	0	1
	Construction Innovation	1	0	0	1	1
	Discover Applied Sciences	0	0	1	0	0
	Energy and Built Environment	0	0	1	0	0
	Engineering, Construction and Architectural Management	1	0	1	3	0
	Environmental Science and Pollution Research	0	0	0	0	1
	Frontiers in Built Enviroment	0	0	0	1	0
	Heliyon	1	0	0	0	0
	IEEE Access	0	1	0	0	0

Research method		Survey	Case Study	Literature Review	Model	Mixed / Other
	IEEE Internet of Things Journal	0	0	0	1	0
	IEEE Transactions on Industrial Informatics	0	0	1	0	0
	Infrastructures	0	0	0	0	1
	International Journal of Ambient Computing and Intelligence	0	0	1	0	0
	International Journal of Building Pathology and Adaptation	1	0	0	0	0
	International Journal of Construction Education and Research	0	0	1	0	1
	International Journal of Construction Management	0	0	1	1	0
	International Journal of Environmental Research and Public Health	1	0	0	0	0
	International Journal of Quality & Reliability Management	0	0	0	0	1
	Journal of Building Engineering	0	0	0	1	0
	Journal of Cleaner Production	1	0	0	0	0
	Journal of Facilities Management	0	0	0	1	0
	Journal of Information Technology in Construction	1	0	0	0	0
	Journal of Organizational Change Management	0	0	0	0	1
	Journal of the Malaysian Institute of Planners	1	0	0	0	0
	Malaysian Construction Research Journal	0	0	0	1	1
	Production Planning & Control	1	0	0	0	0
	Results in Engineering	1	0	0	0	0
	Smart and Sustainable Built Environment	1	0	0	0	0
	Sustainability	1	0	0	1	0
	Technology in Society	0	0	0	0	1
Country	South Africa	1	0	0	1	0
	Germany	0	0	1	0	0
	Saudi Arabia	0	0	0	0	1
	Australia	1	0	0	0	0
	Canada	1	0	0	0	0
	China	1	1	0	3	0
	International collaboration	3	0	1	0	1
	Slovakia	0	0	0	0	1
	United States	1	0	0	0	1
	India	1	0	4	1	3
	Malaysia	3	0	0	1	1
	Nigeria	2	0	0	2	1
	Norway	0	0	0	0	1
	New Zealand	0	0	1	0	1
	Pakistan	0	0	0	1	0
	Kenya	0	0	0	1	0
	United Kingdom	0	0	1	1	1
	Dominican Republic	0	0	0	1	0
	Russia	0	0	1	0	0
	Singapore	1	0	0	0	0
	Vietnan	0	0	0	1	0

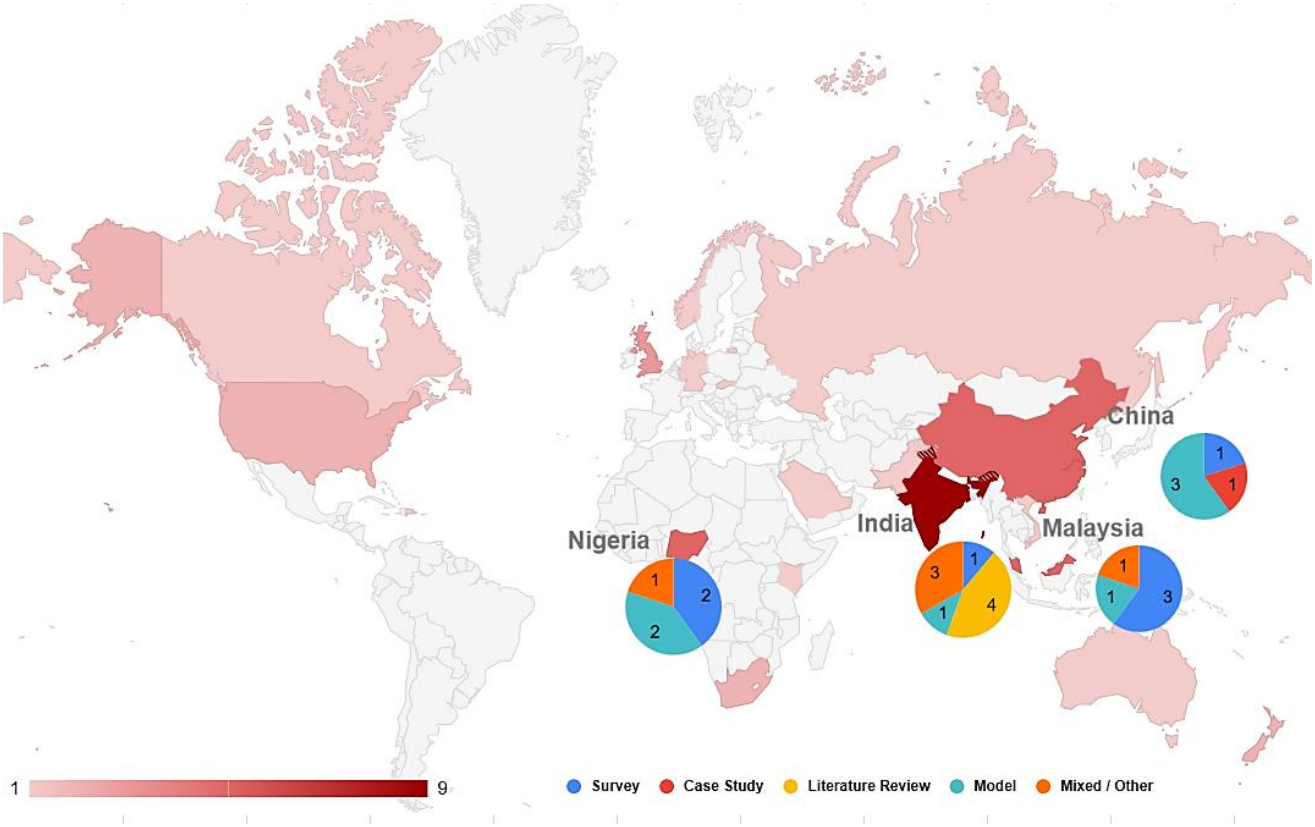

Fig. 4. Distribution of articles by geographic representation on the map and by research method

The geographic distribution demonstrates that studies on digital technologies in Construction 4.0 are conducted across multiple regions, with a concentration in emerging economies. Countries with the highest number of publications also present methodological diversity, particularly survey and modelling approaches.

The temporal distribution of the publications was also analysed based on the portfolio of studies presented in Table 2 and Table 3. Figure 5 illustrates the evolution of research methods over the analysed period.

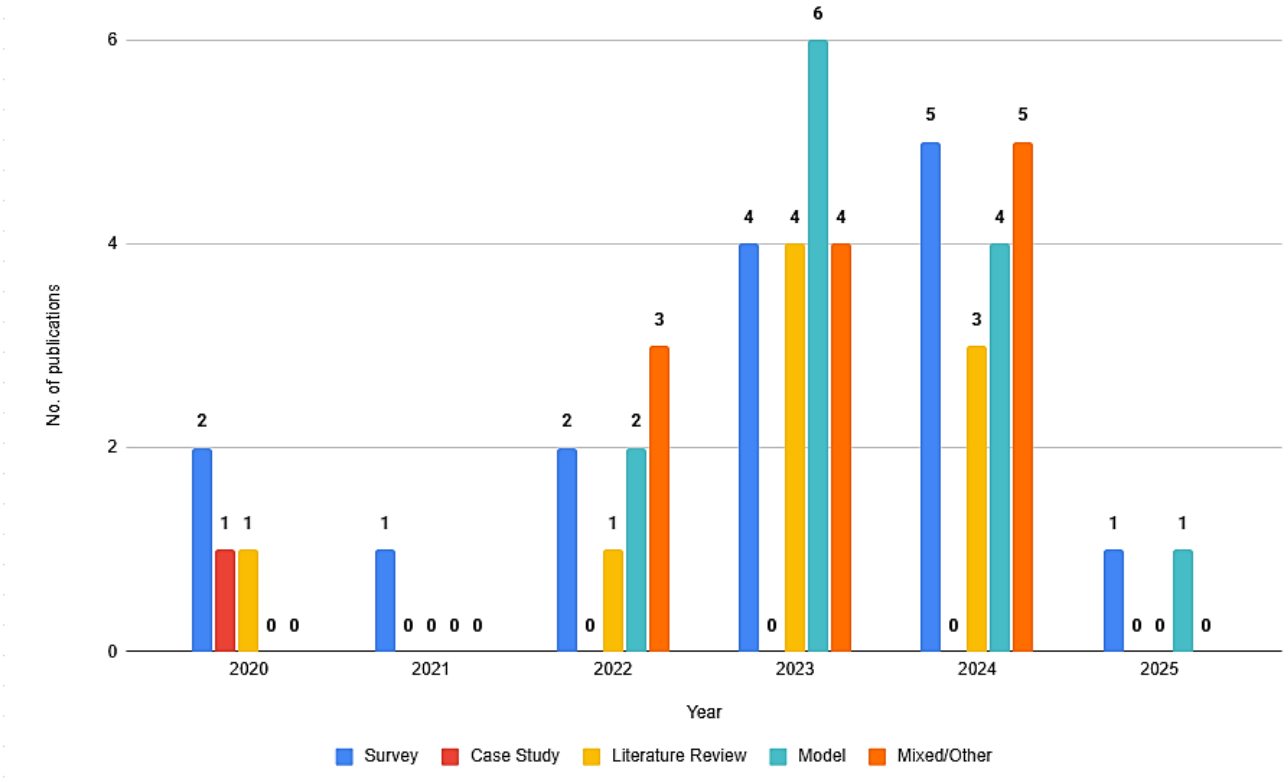

Fig. 5. Distribution of publications by year of publication and research method employed

Between 2016 and 2019, no studies were identified that directly related digital technologies and computerised systems to early-stage real estate development within the context of Construction 4.0. From 2020 onwards, the number of publications increased considerably, indicating an intensification of research activity on digital transformation in the construction industry.

The years 2023 and 2024 concentrated the largest share of publications, with 18 and 17 articles, respectively, corresponding to 36% and 34% of the sample. During this period, modelling approaches became more frequent, particularly in 2023. This recent acceleration indicates that digital transformation in construction remains an emerging research domain, particularly regarding applications beyond construction execution and into strategic pre-construction activities.

Regarding publication outlets, the studies were distributed across 35 journals, highlighting the field's interdisciplinary character. The journals with the highest number of publications include Engineering, Construction and Architectural Management (5 articles), Buildings (4 articles), and Automation in Construction and Construction Innovation (3 articles each).

The authorship analysis identified 169 distinct authors in the selected studies, indicating a relatively dispersed research community. Figure 6 presents the authors with the highest publication frequency.

The most recurrent authors were Bajpai and Misra, each with three publications, while other recurrent authors contributed two publications each. Most studies were developed through collaborative research partnerships, frequently involving emerging economies.

Based on the keywords extracted from the selected publications, Figure 7 presents a word cloud highlighting the most frequent technological terms.

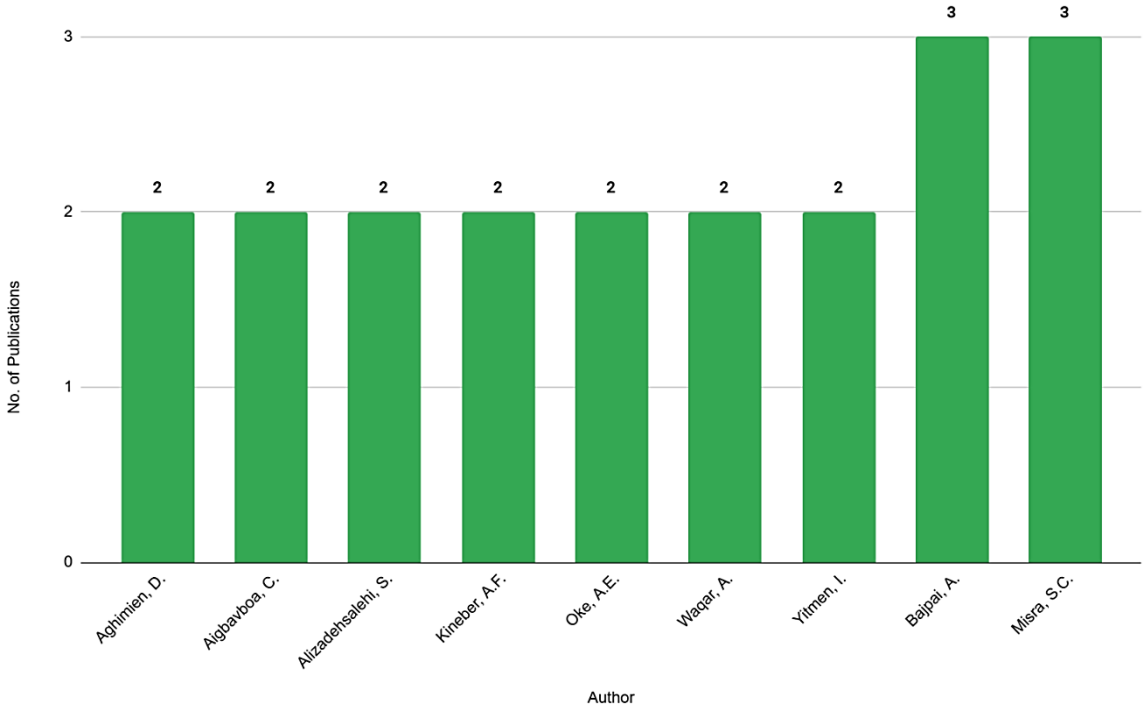

Fig. 6. Distribution of publications by the most recurrent authors

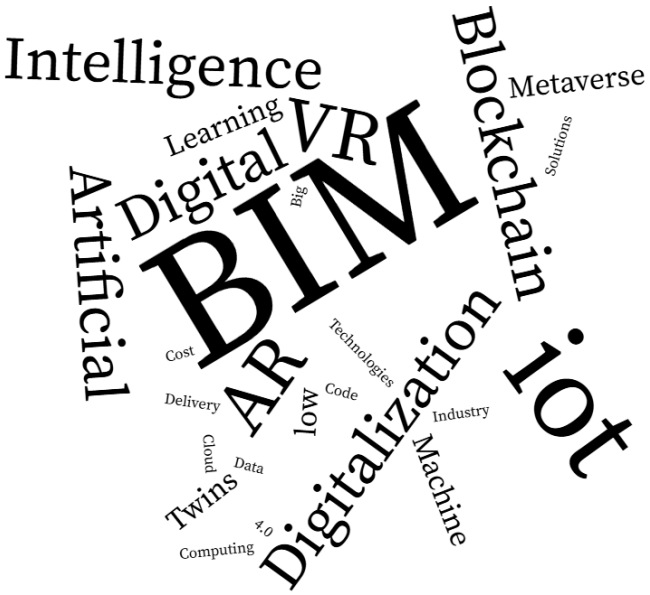

Fig. 7. Word cloud of the most frequent keywords in the selected publications

The results indicate that Building Information Modelling (BIM) is the most frequently addressed technology in the analysed publications. Other recurrent themes include digitalisation, blockchain, Internet of Things (IoT), and augmented and virtual reality (AR/VR). The recurrent keywords identified in the selected studies also reveal thematic clustering patterns within the literature. BIM and digital integration technologies appear strongly associated with collaboration and information management processes, while AI, Big Data, and predictive analytics are predominantly linked to decision-support applications. Digital twins and IoT are mainly related to lifecycle monitoring and smart systems integration, whereas blockchain studies emphasise transparency, traceability, and transactional security.

Finally, the scientific impact of the selected studies was evaluated using citation counts from Google Scholar as of July 13, 2025. The most cited study presented 313 citations [81], followed by studies with 250 [83] and 161 citations [63]. Based on these data, a Pareto chart was developed to analyse the concentration of citations within the portfolio, according to Fig. 8.

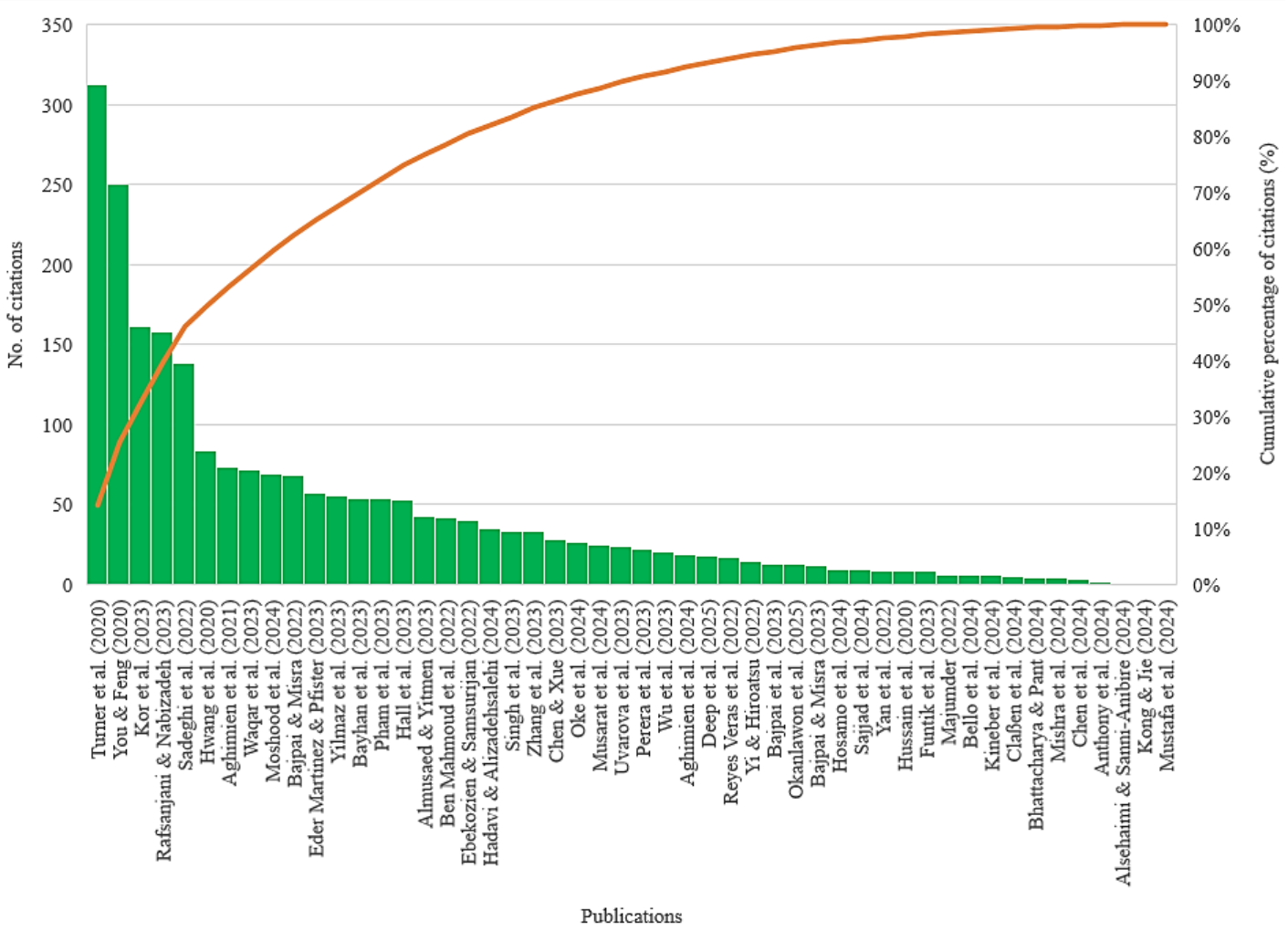

Fig. 8. Pareto chart of the citation distribution of the articles selected in the SLR

Overall, the quantitative results reveal a rapidly expanding and geographically diverse research field. The bibliometric patterns identified in the analysed portfolio provide the basis for the qualitative synthesis presented in the following section.

3.2. Qualitative results

The qualitative analysis examined how the selected studies address the application and strategic role of digital technologies and computerised systems in the early-stage real estate development within the Construction 4.0 context.

To ensure alignment with the research objectives, the qualitative results were structured according to the two research questions defined in the review protocol.

3.2.1. Application of digital technologies in the early-stage real estate development

The reviewed literature identifies several digital technologies applied to activities associated with the real estate development and construction lifecycle. Among the most frequently discussed technologies are Building Information Modelling (BIM), artificial intelligence (AI) and machine learning, blockchain, digital twins, Internet of Things (IoT), augmented and virtual reality (AR/VR), and big data analytics.

Studies focusing on BIM highlight its role as a central platform for integrating and coordinating information among stakeholders, supporting data management and collaborative processes during project planning and development [53–61]. Research addressing artificial intelligence and machine learning

explores their use in predictive modelling, decision-support systems, and performance optimisation in construction-related processes [62–68].

Another emerging area concerns digital twins and immersive environments, which are explored as tools for lifecycle simulation and visualisation of construction projects within integrated digital environments [69–73]. Blockchain technologies are discussed as mechanisms for improving transparency, traceability, and security in contractual and transactional processes related to construction and real estate operations [74–77].

Technologies traditionally associated with Industry 4.0, such as robotics and additive manufacturing, appear primarily in studies addressing construction automation and digital fabrication processes [78–80]. Additionally, several studies emphasise the role of big data and digital frameworks in supporting data-driven decision-making and improving organisational digital maturity in construction companies [81–86].

The reviewed studies indicate that these technologies are not implemented in isolation, but rather tend to operate as interconnected digital ecosystems. BIM frequently appears as the central information management platform, while AI, IoT, digital twins, and big data analytics function as complementary technologies that expand analytical, predictive, and monitoring capabilities across different stages of the real estate development.

3.2.2. Strategic role of digital technologies and computerised systems in the early-stage real estate development

Beyond their operational applications, digital technologies are increasingly recognised as strategic enablers of digital transformation in the construction sector. The literature highlights their potential to improve information integration, enhance collaboration among stakeholders, and support more informed decision-making processes throughout the project lifecycle.

However, several studies also identify barriers to digital transformation in the construction industry. Common challenges include high implementation costs, lack of specialised technical expertise, organisational resistance to technological change, and limited digital infrastructure, particularly in developing economies [88–96].

Institutional and policy initiatives are also discussed as important drivers for technology adoption. Regulatory frameworks and national digitalisation strategies can facilitate the diffusion of Construction 4.0 technologies across the sector [97–98].

Finally, the literature highlights connections between digitalisation, sustainability, and operational efficiency. Some studies link digital technologies with Lean Construction practices and improvements in environmental performance in construction projects [99–100]. In the real estate market, AR/VR technologies are also explored as tools to improve visualisation, marketing, and the customer experience in property commercialisation processes [101]. Another initiative identified in the literature is the Integrated Digital Delivery (IDD) framework, which promotes the integration of digital technologies and collaborative processes across the project lifecycle [102].

4. Discussions

The results of the SLR reveal a growing body of literature addressing digital technologies within the Construction 4.0 paradigm. The quantitative analysis indicates a significant increase in publications after 2020, suggesting that the digital transformation of the construction sector has become an increasingly relevant research topic. These findings corroborate the bibliometric evidence presented in the results section, which shows a rapid increase in publications and the emergence of multiple technological approaches associated with Construction 4.0.

This temporal evolution also suggests a gradual thematic transition in the literature, from initial studies predominantly focused on BIM adoption and construction automation toward more recent discussions involving AI, digital twins, blockchain, data-driven decision-making, and integrated digital ecosystems associated with strategic development activities.

The bibliometric findings also demonstrate a geographically diverse research landscape, with a strong presence of studies conducted in emerging economies, including India, China, Malaysia, and Nigeria. This trend reflects these countries' growing interest in adopting digital technologies to improve efficiency and competitiveness in the construction sector.

From a technological perspective, the qualitative analysis indicates that BIM remains the most consolidated digital technology in the literature, functioning as a central platform for information integration and coordination across project stakeholders [53–61]. The widespread discussion of BIM reflects its strategic role in enabling digital collaboration and data management throughout the project lifecycle.

Other technologies, such as artificial intelligence, blockchain, digital twins, and IoT, are increasingly explored as complementary tools capable of enhancing data analysis, automation, and information transparency in construction-related processes [62–77]. At the same time, immersive technologies such as AR/VR have demonstrated potential applications in visualisation, simulation, and marketing within the real estate market [101].

The findings also suggest different levels of technological maturity across the identified solutions. BIM represents the most consolidated and widely adopted technology, while digital twins, blockchain, metaverse applications, and AI-driven predictive systems still appear as emerging approaches with more limited implementation in early-stage real estate development.

Despite these advances, the literature remains predominantly focused on the production process, particularly activities related to construction execution and automation. Technologies such as robotics and additive manufacturing are primarily discussed in the context of construction site operations rather than in the early stages of real estate development [78–80].

This distinction is particularly important because early-stage real estate development involves predominantly strategic, financial, legal, and market-oriented decisions, whereas the production process is primarily operational and execution-oriented. Consequently, the technological demands of early-stage development differ substantially from those associated with construction site automation and production management. While construction-phase digitalisation is strongly driven by productivity, monitoring, and operational efficiency, early-stage digitalisation requires technologies that support uncertainty reduction, predictive analysis, feasibility assessment, and strategic decision-making.

Consequently, relatively few studies explicitly address the application of digital technologies in the subprocesses of the early-stage real estate development, such as market research and product definition, feasibility analysis, land acquisition, and project launch. This imbalance highlights an important research gap, suggesting the need for further investigations into how

digital technologies can support decision-making and strategic planning in the early stages of real estate projects.

One possible explanation for this imbalance is that Construction 4.0 research has historically evolved around production efficiency and construction automation, where technological applications are more tangible and measurable. In contrast, early-stage real estate development subprocesses are characterised by higher levels of uncertainty, fragmented information, market dependency, and strategic decision-making activities that are comparatively more difficult to standardise and digitalise.

Additionally, the literature consistently reports several barriers to digital transformation in the construction sector. These include high implementation costs, lack of technical expertise, organisational resistance to innovation, and limited digital infrastructure, particularly in developing regions [88–96].

Finally, institutional initiatives and policy frameworks appear to be relevant drivers of the adoption of digital technologies in the construction industry. Government-led digitalisation strategies and regulatory support may play a key role in accelerating the implementation of Construction 4.0 technologies across the sector [97–98].

4. Conclusions

This study demonstrates that the digital transformation associated with Construction 4.0 has increasingly expanded beyond construction execution and begun to influence strategic and decision-oriented subprocesses of early-stage real estate development. By combining bibliometric analysis and qualitative synthesis, the research identified technological trends, adoption patterns, maturity levels, and important research gaps related to the application of computerised systems in the early-stage real estate development.

The bibliometric results indicate a significant increase in publications from 2020 onward, reflecting the growing relevance of digital transformation in the construction sector. Most studies originate in developing countries such as India, China, Malaysia, and Nigeria, while contributions from South America remain limited, highlighting opportunities to expand empirical research in regional markets such as Brazil.

The qualitative analysis shows that several technologies associated with Construction 4.0 are gradually being incorporated into early stages of real estate development. Applications include Big Data and predictive analytics for market analysis, machine learning for feasibility studies, blockchain for land acquisition and document traceability, and augmented reality, digital twins, and simulation tools to support project launch and commercialisation. These technologies contribute to transforming traditionally fragmented processes into more integrated and data-driven decision environments. Among the identified technologies, BIM appears as the most consolidated digital solution, while digital twins, blockchain, and AI-driven systems still demonstrate lower maturity levels and more limited implementation in early-stage development subprocesses.

However, the literature remains largely conceptual, with limited empirical evidence regarding the implementation of integrated computerised systems across the development process. Most studies focus on technologies applied during production and post-construction stages, while earlier stages such as feasibility analysis, land acquisition, and legal approval remain underexplored.

This imbalance suggests that Construction 4.0 research remains predominantly centred on operational efficiency and construction automation, whereas strategic, financial, legal, and market-oriented subprocesses of early-stage development still present lower levels of digital integration and technological maturity. Barriers to adoption also persist, including limited interoperability between systems, restricted access to reliable data, lack of standardisation, financial constraints, and insufficient workforce training.

From a theoretical perspective, this study contributes by systematising research on Construction 4.0 technologies applied specifically to the early-stage real estate development and by relating these technologies to the technological pillars of Construction 4.0. From a practical perspective, the findings indicate that computerised systems can support more integrated, transparent, and data-driven approaches to market analysis, feasibility assessment, risk reduction, licensing management, and investment decision-making in early-stage real estate development. The study also highlights the importance of institutional support, digital governance strategies, and professional training to accelerate the adoption of Construction 4.0 technologies across the sector.

Future research should investigate the practical implementation of integrated digital ecosystems combining BIM, AI, IoT, digital twins, and data analytics in early-stage real estate development. Additional empirical studies are also needed to evaluate the impacts of these technologies on organisational performance, risk mitigation, feasibility analysis, and strategic decision-making activities, particularly in emerging markets where digital transformation remains uneven.

From a practical perspective, the findings suggest that policymakers should promote regulatory frameworks, digital governance strategies, and institutional incentives to support the adoption of integrated computerised systems in early-stage real estate development. For organisations and industry professionals, investments in interoperability, professional training, and data-driven decision-support systems may improve strategic planning, transparency, and operational integration across the real estate development lifecycle.

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