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Construction 5.0 and digitalisation in the construction sector: Identification of research gaps and barriers to the implementation of digital tools

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ABSTRACT

The construction sector, accounting for approximately 9% of global GDP, is undergoing transformation driven by the Industry 5.0 (I5.0) paradigm, which emphasises three pillars: human-centricity, sustainability and resilience. Construction 5.0 (C5.0) applies these principles to construction, integrating digital twins (DT), building information modelling (BIM), the internet of things (IoT), and artificial intelligence (AI) with the human-centric values of the Society 5.0 framework. This article aims to: (1) synthesise the organisational and practical barriers and enablers shaping C5.0 implementation; (2) characterise common data environment (CDE) tools as construction's information infrastructure; (3) identify dominant thematic clusters in the literature; and (4) indicate key research gaps in the empirical integration of C5.0's technological and social dimensions. Five thematic clusters were identified: cyber-physical technologies and digital twins; CDE as information infrastructure; Society 5.0 and the social dimension; sustainability and resilience; and quality management. CDE, standardised under ISO 19650, emerged as a vital information layer linking BIM, digital twins, and IoT sensors into a coherent, real-time data ecosystem. The most critical research gaps identified are the absence of empirical studies on DT–CDE integration during construction execution, insufficient research on the social dimension of digital transformation, and weak integration of all three I5.0 pillars within single studies – particularly evident in the Central and Eastern European context. The article contributes to a small but growing body of reviews jointly considering the C5.0, CDE, and Society 5.0 perspectives.

Keywords: Construction 5.0, Industry 5.0, common data environment, Society 5.0, digital twin, building information modelling, construction innovation.

INTRODUCTION

The construction sector, responsible for approximately 9% of global gross domestic product and generating global expenditure of around USD 11 trillion per year, is undergoing a profound transformation driven by the latest industrial revolution [1,2]. The concept of Industry 5.0 (I5.0), formalised by the European Commission in 2021, goes beyond the fourth industrial revolution paradigm by emphasising three interrelated pillars: human-centricity (placing people at the heart of technological processes), sustainability (environmental and social sustainability), and resilience (the capacity of industrial systems to adapt) [3,4]. The concept represents a response to critiques of Industry 4.0, which was seen as allowing technological determinism to marginalise the role of workers and overlook the broader socio-environmental context of innovation.

In the context of the construction sector, this phenomenon takes the form of Construction 5.0 (C5.0) – a paradigm integrating advanced technologies (artificial intelligence, the internet of things, digital twins, robotics, blockchain) with

humanistic and ecological values [5,6]. While Industry 4.0 introduced building information modelling (BIM), 3D printing, and process automation to construction [7,8], C5.0 raises fundamental questions about the social rationale and environmental consequences of that automation. As Ikudayisi et al. [9] note, this transformation requires a new relationship between humans and technology – one in which the construction worker remains an active participant in the digital ecosystem rather than a passive recipient of automation. The embodiment of this paradigm shift is the Society 5.0 concept, which – as the social counterpart of Industry 5.0 – calls for the integration of technology with social goals and human well-being.

Despite the dynamic growth in publications on C5.0 – Akhavan and Alivirdi [1] record 78 articles from 2022–2025 in Scopus – the body of empirical research remains limited and the field itself fragmented.

The construction 5.0 concept and its theoretical foundations

Industry 5.0 was formalised by the European Commission as a concept complementary to, rather than replacing, Industry 4.0 [3]. Its three pillars – human-centricity, sustainability, and resilience – set a new agenda for the manufacturing sector, including construction. Systematising literature stresses that I5.0 is not merely the next stage of technological evolution but an attempt to reintegrate human and environmental values into the architecture of production systems [4,10]. Musarat et al. [6] and Yitmen et al. [5] proposed transposing these principles directly to Construction 5.0, defining C5.0 as a paradigm of a technologically advanced construction sector focused on harmonious human–robot collaboration, a sustainable construction environment, and the capacity to respond to external disruptions (pandemics, resource crises, climate change). Ghobakhloo et al. [11] similarly extend these principles toward sustainability goals for production sectors, including construction [12].

Bibliometric analyses reported in the cited literature [1,13] indicate dynamic growth in interest in C5.0: whereas only sporadic works appeared before 2022, the years 2023–2024 brought a sharp increase in articles. The scientific maturity of the C5.0 concept is, however, considerably lower than that of C4.0, which opens space for original empirical and conceptual research [14].

Identifying the above literature streams shaped the logic behind the six search strings used in this review. Each search tag derives directly from the literature – these are areas identified by researchers as scientifically important and as yet insufficiently integrated. (1) “Industry 5.0” AND “Construction” – the foundational search string set by the European Commission’s formalisation of I5.0 [3] as the overarching research paradigm; this tag captures works directly linking the I5.0 agenda to the construction sector. (2) “Construction 5.0” – a dedicated tag introduced by Musarat et al. [6] and Yitmen et al. [5], who were among the first to formalise C5.0 as a distinct paradigm; without this string, works using the term as a proper label would have been missed. (3) “Society 5.0” AND “Construction” – motivated by the complementarity of Society 5.0 and Industry 5.0 documented by Huang et al. [15] and Yitmen et al. [5]. Tunji-Olayeni et al. [16] were among the first to conduct a bibliometric analysis of Industry 5.0 and Society 5.0 research trends applied directly to construction; without this tag, works analysing the social dimension of digital transformation – underrepresented in general I5.0 search results – would have been overlooked. (4) “Digital twin” AND “Construction” AND “Industry 5.0” – derives from the identification of DT as one of the central cyber-physical technologies of C5.0 [17,18]; adding “Industry 5.0” as a third operand restricts results to papers that explicitly connect DT applications to the I5.0 paradigm, rather than generic construction DT studies. (5) “Construction” AND “Resilience” AND “Industry 5.0” – reflects the resilience pillar of I5.0 in the construction context; the tag captures works that connect the adaptive capacity of construction systems with the I5.0 framework [11,19], covering both sustainability and resilience dimensions. (6) “Common Data Environment” AND “Construction” – defined in ISO 19650 as BIM’s information infrastructure – constitutes a necessary integration layer for the remaining C5.0 technologies; this tag enabled access to specialised normative and implementation literature [20–22] that does not appear in general I5.0 search results. Common data environment (CDE) publications were included in the corpus even where they do not use Industry 5.0 or Construction 5.0 terminology directly, because CDE constitutes the operational, implementation-level layer through which the three I5.0 pillars are realised in practice: shared, versioned project information underpins

human-centricity by giving all stakeholders – including on-site workers – equal access to current data; it reduces rework and material waste, supporting sustainability; and it enables the real-time responsiveness that underlies resilience. The review therefore treats CDE literature as evidence of how C5.0 principles are operationalised, rather than requiring that source publications adopt C5.0/I5.0 terminology themselves. This selection of strings ensures coverage of all three I5.0 pillars (human-centricity: tag 2; Society 5.0 and social dimension: tag 3; sustainability and resilience: tag 5; information management: tag 6), while also capturing literature using both the broader term Industry 5.0 and the narrower Construction 5.0 (tags 1 and 2).

Despite its critical economic significance, construction remains one of the least digitalised sectors of the economy. Jäkel et al. [23] indicate that compared with the automotive and manufacturing sectors, construction exhibits structural digital underdevelopment, a finding confirmed by the RICS Digitalisation in Construction 2024 report [24] – only 12% of respondents consistently apply digital tools across all projects. Barbosa et al. [25] document that large construction projects are completed on average 20% later than planned and up to 80% over budget, leaving construction among the least productive sectors of the global economy. The direct cause is the absence of current, shared information: Ramadhan et al. [26] show that unplanned design changes account for 56.5% of cost overruns and 40% of schedule delays on large projects. A further dimension of this problem is rework – the need to repeat completed works – which consumes an estimated 5–12% of total project costs [27] and is one of the main drivers of cost growth and tensions among construction participants. The digital skills gap among workers deepens this deficit further [23,24]. In this context, CDE tools emerge as a systemic response to the information availability problem – a shared, versioned data repository enabling all project participants to make decisions based on current, reliable data [28–30].

The aim of this article is to synthesise the organisational and practical barriers and enablers shaping the implementation of the Industry 5.0 concept in the construction sector (Construction 5.0), to identify dominant technological trends, and to indicate the research gap.

STATE OF RESEARCH, KEY TRENDS AND THE ROLE OF CDE

Cyber-physical technologies, digital twins and common data environment

The leading thematic cluster in the analysed literature is the integration of cyber-physical technologies: artificial intelligence (AI), the Internet of Things (IoT), digital twins (DT), and building information modelling (BIM). A number of reviews document the convergence of these technologies: Baghalzadeh et al. [18] map the network links between IoT, BIM, and DT in construction; Shahzad et al. [31] and AlBalkhy et al. [32] systematise DT applications in the built environment. Earlier work by Opoku et al. [33] had already analysed DT applications across the entire building lifecycle. Ikudayisi et al. [9] identify BIM and DT as the key instruments of C5.0, enabling continuous monitoring of building condition and dynamic management of construction processes throughout the lifecycle. Wang et al. [17] present a workflow based on a closed-loop BIM–DT system in which AI-supported robotic systems enable automated monitoring of construction progress and site safety. The review by Hu et al. [34] confirms that DT–BIM integration spans all lifecycle phases, with studies concentrating primarily on the construction and operation stages. Wang et al. [35] demonstrated how BIM models can be rendered in a virtual reality (VR) environment coupled with a real-time digital twin.

Despite confirmed implementation potential, the literature identifies significant adoption barriers: high implementation costs, difficulties integrating data from heterogeneous systems, a digital skills gap, and concerns over the privacy and security of project data [36,37]. The interoperability challenge for DT and BIM platforms remains one of the field's key technical hurdles.

A critical yet still insufficiently understood element of the digital construction infrastructure is the common data environment – the shared data environment defined in ISO 19650-1:2018 [38] as the agreed source of information for any given project or asset, used to collect, manage, and share each information container within a managed process (Jaskula et al. [20]). CDE constitutes the information layer binding BIM, digital twins, and IoT systems into a coherent,

real-time data ecosystem accessible to all project stakeholders. Under ISO 19650, information containers pass through four states: Work in Progress (WIP – information being prepared), Shared (for coordination), Published (approved for use), and Archived. This mechanism ensures data integrity and eliminates the problem of concurrently functioning, contradictory documentation versions – a phenomenon particularly acute on active construction sites.

Society 5.0 and the social dimension of digital transformation in construction

In parallel with the Industry 5.0 concept, the Japanese government initiated the Society 5.0 concept – a vision of a super-smart society in which advanced digital technologies serve directly to solve social problems [39]. Narvaez Rojas et al. [39] had earlier defined Society 5.0 as a human-centred model of society in which the digital and physical spheres are tightly integrated. Huang et al. [15] demonstrate that Industry 5.0 and Society 5.0 are complementary and mutually reinforcing concepts: I5.0 provides the technological framework, while S5.0 defines the social context of transformation.

In the construction context, transposing the principles of Society 5.0 implies a fundamental revaluation of the role of workers in a digital environment. Yitmen et al. [5] were the first to integrate Operator 5.0, Society 5.0, and Construction 5.0 in a single model, arguing that effective transformation of construction requires not only the deployment of technological tools but also the building of a digital–social ecosystem. Tunji-Olayeni et al. [16] conducted a bibliometric analysis of Industry 5.0 and Society 5.0 research trends in construction, identifying health and safety, collaborative working, and waste management as key application areas, and indicating that achieving the UN Sustainable Development Goals (SDGs) in construction requires simultaneously addressing the technological and social dimensions of transformation.

The social dimension of digital transformation in construction encompasses several key aspects. Gamberini and Pluchino [40] document that I5.0 and S5.0 redefine the work environment, placing emphasis on cognitive ergonomics, workers' health and safety, and the dignity of work. Daoud et al. [41] point out that implementing I5.0 in infrastructure requires ensuring the inclusiveness of digital transformation for workers with lower digital competencies. Davila Gonzalez and Martin [42] similarly foreground worker well-being through a dedicated digital-twin concept, discussed further below.

A key finding from the literature review is that the social dimension of digital transformation in construction remains far less developed in research terms than the technological dimension. Ghobakhloo et al. [43] map the contribution of I5.0 transformation to the achievement of the SDGs, but their roadmap remains at the level of manufacturing sectors, without exploring the specifics of construction. Jäkel et al. [23] document that the digital backwardness of construction is not merely a technological issue but primarily a social and organisational one. Without addressing this social layer – in keeping with the spirit of Society 5.0 – no technical infrastructure, including CDE, will achieve its full operational potential.

Sustainability and resilience

Sustainability, the second pillar of I5.0, is widely reflected in the C5.0 literature. Ikudayisi et al. [9] stress that C5.0 places sustainability at the heart of building design and delivery, encompassing carbon footprint reduction, energy efficiency, circular economy, and the well-being of construction workers. Dobrucali et al. [44], analysing critical success factors for sustainable construction implementations, identify management commitment and clear regulatory requirements as priority factors. Ghobakhloo et al. [11] map the contribution of I5.0 to the UN SDGs, identifying cobots, AI, and knowledge management as the most important technologies generating environmental and social value. Earlier work by Longo et al. [45] argued that value-oriented and ethical technology engineering – central to I5.0 – requires consideration of worker dignity, autonomy, and fairness alongside process efficiency. Earlier work by Chileshe et al. [46], surveying construction practitioners, identified cost, regulatory restrictions, and legal liability as the most significant barriers to implementing reverse logistics and circular-economy practices in construction – barriers directly relevant to realising the circular-economy dimension of C5.0 sustainability.

Review findings indicate, however, that the majority of analysed publications treat the three I5.0 pillars as independent research domains:

technological analyses rarely incorporate a social perspective and environmental impact assessment, while works on construction sustainability rarely account for the human-centricity and Society 5.0 dimensions. Specifically, sustainability and resilience appear in the analysed corpus predominantly as a distinct research stream, addressed through management, regulatory, and process-level lenses [44,45], rather than as a concern integrated with the technological literature on digital twins, IoT, and CDE reviewed above; only a small minority of publications [11,43] explicitly connect sustainability outcomes to specific enabling technologies. The weak integration of all three pillars within a single research or implementation project is one of the central conclusions of this review and directly defines the research gap.

Quality management and Construction 5.0

Quality management remains a relatively under-researched area at the intersection of I5.0 and construction. Aghimien et al. [47], analysing the digitalisation of construction firms in developing countries, identify information management as the key competency conditioning the effectiveness of digital transformation, including quality management. Davila Gonzalez and Martin [42] develop the concept of the Human Digital Twin as a tool for monitoring worker well-being in accordance with Society 5.0 postulates – an instrument linking human-centricity with quality management of the construction process. Chen et al. [48] document the impact of wearable devices on construction workers' safety, identifying exoskeletons and smart PPE as key technologies for quality and occupational safety monitoring in the C5.0 context. Yue et al. [36], in a review of DT applications in construction quality management, highlight growing applications of DT–IoT systems for real-time quality monitoring, defect detection using computer vision, and technological process control. Nevertheless, the authors note that the integration of DT with human-centric quality management (HCQ) – accounting for the human factor and worker technology acceptance – remains practically unexplored. This gap is all the more significant given that the effectiveness of technological implementations in construction is largely determined by user acceptance and the organisational culture of construction firms, as confirmed by model-based research [29].

Common data environment as information infrastructure of Construction 5.0

CDE is the central information management tool in a BIM-based construction environment. The ISO 19650 standard series – defining information management using BIM – introduces CDE as a mandatory element of information organisation in any construction project complying with its requirements. In practice, CDE is a cloud or server-based platform (e.g., Dalux, Autodesk Construction Cloud, Procore, Trimble Connect, 4Projects) integrating BIM models, technical documentation, schedules, site diaries, inspection records, Requests for Information (RFI), and IoT sensor data in a single, structured repository [20,21]. The CDE concept originates from the British standard BS 1192:2007 [49]; its evolution through PAS 1192-2:2013 [50] to the ISO 19650 series (2018) established it as the global standard for building asset information management.

In the Construction 5.0 context, CDE performs the role of an information layer without which the integration of advanced technologies – digital twins, IoT sensors, and real-time quality management systems – loses operational coherence. Earlier work by Patacas et al. [22] had demonstrated that a CDE built on open standards (IFC, openCDE API) constitutes the foundation of interoperability among different design and management applications throughout the entire building lifecycle. Seidenschnur et al. [51] presented a CDE implementation for HVAC installation management, demonstrating that continuous synchronisation of design and operational data within a single data environment reduces clash occurrences and accelerates decision-making. Dolla et al. [21], studying CDE deployment on a flagship educational project in India using action research, found that institutional pressures (regulatory, normative, and culturally-cognitive) significantly shape the CDE adoption process and determine the actual extent of the data environment's use during project execution.

Jaskula et al. [20], in the first comprehensive state-of-the-art review on CDE combining analysis of 46 documents with interviews with 15 BIM experts, identified project complexity and the simultaneous use of multiple CDE environments (multi-CDE) as the key barriers to practical implementation. The authors indicate that data concerning accountability, transparency, and information trustworthiness represent the most

serious challenge in multi-platform construction projects. The proposed solution is the integration of blockchain technology as a mechanism ensuring the immutability and auditability of records in a multi-CDE environment. This diagnosis is particularly significant from the C5.0 perspective: a DT system operating on the basis of outdated or inconsistent geometric data generates a risk of decision-making and execution errors, the likelihood of which increases with the number of concurrently operating repositories. Earlier work by Tao et al. [52] had been among the first to propose a decentralised CDE environment based on blockchain and IPFS (InterPlanetary File System), eliminating the need for a central server and enhancing the security of BIM data exchange.

Despite the growing body of research on CDE in the design phase, the implementation of common data environments on active construction sites – by workers, machine operators, and foremen, not solely by designers and project managers – remains a poorly explored area. Most existing studies focus on design and planning phases, without analysing how CDE data can be shared and used in real time by physical workers directly during task execution [20,21]. This gap represents one of the central deficits in the field.

IDENTIFICATION OF RESEARCH GAPS

On the basis of the analysis of 37 publications from 2022–2025 and the synthesis of thematic coding results, six key observations regarding deficits in construction innovation research in the Industry 5.0 era can be formulated (Table 1). Throughout the six gaps below and in Table 1, references to an "absence" or "lack" of research denote that such work was not identified within the corpus analysed in this review; this is an important limitation resulting directly from the selected database, time frame, and search strategy.

First, the dominance of conceptual and review studies over empirical research. Of the 37 core-corpus publications, 13 (~35%) are literature reviews or bibliometric studies, 9 (~24%) are conceptual or theoretical papers, 11 (~30%) report original empirical research, and 4 (~11%) combine review and empirical components; conceptual and review-type work therefore accounts for 22 of 37 publications (~59%), compared with 11 (~30%) narrating original empirical findings. The majority of the analysed articles are theoretical-conceptual or bibliometric in character. Empirical studies documenting real-world implementations of C5.0 solutions on construction sites were not identified within the analysed body of literature, making it impossible to verify proposed models against industrial practice conditions [14]. Akhavan and Alivirdi [1] consistently identify this disproportion as one of the field's main deficits. This predominance of conceptual and review-type work carries direct consequences for the maturity of the field: frameworks, roadmaps, and maturity models proposed in the literature remain largely unvalidated against real project data, so their practical applicability, cost implications, and organisational barriers under specific market conditions – such as those of the Polish or Central and Eastern European construction sector – remain untested. Until empirical studies close this gap, guidance for practitioners seeking to implement C5.0 solutions is likely to remain aspirational rather than field-tested.

Second, the lack of integration of the three Industry 5.0 pillars within a single research project. The analysed publications treat human-centricity, sustainability, and resilience as independent domains, precluding the development of holistic C5.0 models that simultaneously address working conditions, environmental impacts, and the adaptive capacity of construction organisations. Ivanov [10] postulates such an approach in relation to I5.0 in general.

Third, an insufficient body of regional research, particularly from Central and Eastern Europe. The dominant research centres in the C5.0 area are Asia (China, India, Malaysia) and Western Europe (United Kingdom, Germany, Spain). Poland and Central and Eastern Europe more broadly are virtually absent from the analysed literature, despite the specific conditions of their construction markets (different enterprise structure, different regulatory regime, varying levels of sector digitalisation). Empirical studies from Sub-Saharan Africa – such as the analysis of mechatronics success factors in AECO in Nigeria [53] – confirm that regional context fundamentally alters both implementation barriers and research priorities.

Fourth, the absence of systematic research on the acceptance and adoption of I5.0 technologies by construction workers and organisations. Implementation barriers identified in the literature (costs, skills gap, organisational culture) are not explored from the perspective of technology acceptance

Table 2. Identified research gaps in the area of construction innovation in the Industry 5.0 era and recommended research approaches

Research gap area	Description of deficit	Recommended research approach
1. Empirical studies of C5.0 technology implementation	Dominance of conceptual and bibliometric studies; lack of case studies documenting real-world deployment of C5.0 technologies (CDE, DT) on construction sites	Case studies, field research
2. Integration of three I5.0 pillars	Human-centricity, sustainability and resilience addressed separately; no holistic models combining all three dimensions within a single project	Longitudinal studies, mixed methods
3. Regional context (Poland)	Dominance of Asian and Western European research; lack of analyses accounting for the specifics of the Polish construction market	National surveys, expert interviews
4. Acceptance of I5.0 technologies	Implementation barriers (competencies, organisational culture) not explored through technology acceptance models	Structured questionnaire, SEM
5. Digital twin in the execution phase (DT–CDE)	No empirical studies on DT–CDE integration during construction execution; DT and CDE studied mainly in design and planning phases	Experimental studies, case study; pilot of a live IFC/openCDE-DT interface with deviation-threshold RFI triggering
6. Social dimension of transformation (Society 5.0)	No research on digital readiness and digital competencies of construction workers in the context of S5.0 transformation; no inclusive digitalisation models for low-skilled workers	Case studies, participant observation, DT–CDE integration protocols

Note: Based on the literature review results (2022–2025). S5.0 – Society 5.0; I5.0 – Industry 5.0; SEM – structural equation modelling.

models [47]. The deployment of advanced digital solutions on construction sites requires not only technical readiness but, above all, organisational and social readiness – which is the central postulate of Society 5.0 [16,39].

Fifth, the absence of empirical research on the integration of digital twins with Common Data Environment during the construction execution phase. Yue et al. [36] indicate that the application of DT–IoT systems for real-time quality management on active construction sites remains empirically unexplored. Shahzad et al. [31] and AlBalkhy et al. [32] confirm that DT–CDE integration during the execution phase – where the model must be updated in real time by workers and measurement systems – constitutes a gap that is both technical and organisational. Concretely, such integration would involve a bidirectional information flow: from the CDE, the digital twin would draw the approved as-designed geometry, specifications, and the status of information containers (Work in Progress, Shared, Published) to establish the baseline against which as-built conditions are compared; conversely, the digital twin would feed back into the CDE real-time as-built data – captured via IoT sensors, laser scanning, or computer vision – together with any detected geometric, schedule, or quality deviations from that baseline. This integration could support concrete decisions during execution: automated progress verification against payment milestones, early triggering of RFIs or corrective work orders once a deviation exceeds a defined tolerance, and predictive flagging of elements at risk of failing formal quality inspection based on observed deviation trends. Realising this would require CDE platforms to expose a live, machine-readable interface – for example via IFC or openCDE APIs – that digital twin systems can query and update in real time, rather than the periodic, manually triggered data exchanges typical of current design-phase CDE implementations.

Sixth, the absence of research on the social dimension of digital transformation in construction in the spirit of Society 5.0. Existing CDE studies focus almost exclusively on the technical aspects of implementation, overlooking the question of acceptance and adoption of these tools by physical workers [20,21]. Empirical studies analysing the following are lacking: (a) the level of digital maturity and social readiness of construction enterprises for transformation consistent with S5.0 postulates; (b) the influence of organisational culture and workers' digital competencies on the effectiveness of CDE and DT deployments; (c) the inclusiveness of digital transformation in construction from the perspective of workers with low digital competencies. This gap is particularly visible in the Central and Eastern European context, where the degree of BIM/CDE adoption and the digital maturity of construction enterprises are markedly lower than in Western European countries [1,54].

The research methods recommended in Table 2 were selected to match established disciplinary standards for each gap's evidentiary requirements. Case study and field research (Gaps one, five, and six) follow Yin's guidance [55] on using case studies to investigate contemporary phenomena within their real-world context, appropriate where implementation practices cannot be isolated from their organisational setting. Longitudinal, mixed-methods designs (Gap two) draw on Creswell and Plano Clark's framework [56] for integrating quantitative and qualitative strands, suited to tracking the integration of the three I5.0 pillars over time. National surveys and expert interviews (Gap three) follow standard survey-methodology guidance [57] for capturing regional variation across a defined population of construction enterprises. Structured questionnaires analysed via structural equation modelling (Gap four) follow established PLS-SEM guidance [58] for testing multi-construct models such as technology-acceptance frameworks. The proposed pilot of a live IFC/openCDE–DT interface (Gap five) follows the design-science research paradigm [59], appropriate for developing and evaluating novel technological artefacts rather than merely observing existing practice. Participant observation combined with DT–CDE integration protocols (Gap six) follows established ethnographic fieldwork guidance [60] for capturing how digital tools are actually used, understood, and adapted by construction workers in situ.

CONCLUSIONS

This article presents synthesising organisational and practical implementation barriers, characterising CDE as information infrastructure, identifying dominant thematic clusters, and indicating key research gaps.

First, the assessment of the research landscape demonstrated that the Construction 5.0 research field is developing dynamically – the number of publications increased sharply after 2022 – yet it remains dominated by conceptual and bibliometric studies, with a clear deficit of empirical work documenting real-world deployments on construction sites.

Second, the characterisation of Common Data Environment tools revealed that CDE – originating from the British standards BS 1192:2007 and PAS 1192-2:2013, codified in the ISO 19650 series – constitutes a key layer of the information infrastructure of the built environment. Analysis showed that CDE functions analogously to a construction project's nervous system: it collects data from IoT sensors, versions BIM models, and distributes current information to all project participants. Contrary to the dominant view in the literature of CDE as a design-phase tool, the review suggests that its operational potential may be more fully realised on active construction sites, particularly in coupling with digital twins.

Third, analysis identified five dominant thematic clusters: (1) cyber-physical technologies and digital twins, (2) common data environment as information infrastructure, (3) Society 5.0 and the social dimension of transformation, (4) sustainability and resilience, (5) quality management and information management.

Fourth, a research gap was identified in the area of empirical integration of the principles of human-centricity, sustainable development, and resilience: the key deficit is the absence of studies combining these three I5.0 pillars in a single research or implementation project, and in particular – the absence of empirical research on DT–CDE integration during construction execution and the absence of research on the social dimension of transformation (Society 5.0). This gap is particularly apparent in the Central and Eastern European context, including the Polish construction market, where both BIM/CDE adoption and the digital maturity of construction enterprises remain markedly lower than in Western European countries or Asia.

This finding also speaks to one of the principal distinctions between Construction 4.0 and Construction 5.0: whereas C4.0 research has been predominantly technology-centred – focused on automation, data integration, and process efficiency – the C5.0 paradigm explicitly foregrounds the human factor, positioning worker well-being, competency development, and technology acceptance as constitutive elements of the paradigm rather than secondary implementation concerns. The scarcity of empirical research on technology acceptance models and employee competencies identified in this review is therefore not merely one gap among several, but one that goes to the core of what differentiates C5.0 from its predecessor: without empirical evidence on how construction workers actually perceive, adopt, and are supported in using digital tools, claims about

C5.0's human-centric character remain largely aspirational rather than demonstrated.

Several structural factors help explain why these gaps persist. The predominance of conceptual and review work (Gap one) reflects both the recency of the C5.0 concept – formalised only since approximately 2022–2023 – and practical barriers to empirical access, including limited availability of pilot sites and confidentiality constraints on active construction projects; publication incentives that reward timely synthesis articles over slower empirical fieldwork may reinforce this further. The weak integration of the three I5.0 pillars (Gap two) likely stems from disciplinary siloing: technologically oriented construction-engineering research and socially oriented management research are typically published in different venues and rarely draw on each other's methods. The regional imbalance (Gap three) plausibly reflects disparities in research funding and publication capacity, compounded by the search strategy's restriction to English-language, Scopus-indexed sources, which may under-represent Polish- and other CEE-language scholarship. The gap in technology-acceptance research (Gap four) may follow from C5.0's human-centric emphasis being a comparatively recent addition to the paradigm, with survey instruments still largely adapted from generic technology-acceptance models rather than purpose-built for construction-site conditions. The absence of empirical DT–CDE integration research during execution (Gap five) plausibly reflects genuine technical immaturity – real-time, site-based data infrastructure remains less developed than design-phase tooling – rather than a simple oversight in the literature. Left unaddressed, these gaps risk leaving Construction 5.0 as a predominantly conceptual framework: implementation guidance would remain untested against real project conditions, worker acceptance and competency needs would go unaddressed in practice, and the field's development would continue to be shaped disproportionately by research conducted outside the Central and Eastern European context.

The conclusions of this review acquire particular significance in the light of the chronic digitalisation deficit in the construction sector. Construction exhibits structural backwardness relative to the automotive and technology industries, and its consequences are measurable: unplanned change orders account for more than half of cost overruns on large projects, while rework consumes an average of 5–12% of contract values. A recurring contributing factor to both pathologies, as reflected in the reviewed literature, appears to be the limited availability of real-time information on the construction site. The progressive adoption of technologies enabling real-time information – IoT sensors, digital twins, and CDE-integrated monitoring – may gradually erode this barrier, but is also likely to introduce new challenges: managing the volume and latency of continuously generated site data, securing systems that remain persistently connected on active construction sites, and building the organisational capacity to act on real-time signals rather than merely collect them. A beacon of hope is the growing application of digital twin and IoT systems for real-time quality management – progress monitoring, defect detection using computer vision, and as-built deviation tracking – laying the foundations for a model of construction in which errors could be detected and corrected considerably faster than under current practice.

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