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DIGITAL TRANSFORMATION IN CONSTRUCTION: EVIDENCE FROM BRAZIL

Laura L. de A. Fernandes[1] & Dayana Bastos Costa[2]

ABSTRACT

Recent industrial revolutions have been transforming industries and society, leading to major changes in the construction sector. Despite significant advances in research on Industry 4.0 and Industry 5.0 in construction in developed countries, the digital transformation of construction industries in less industrialized contexts remains underexplored, especially from a production-stage perspective. Therefore, this study discusses the digital transformation process in construction, drawing on evidence from Brazil. To this end, a Maturity Measurement System (MMS) was applied to six case studies. The MMS assesses digital transformation maturity in construction production using a sociotechnical approach that integrates the principles of Industry 4.0 and Industry 5.0. The results indicate that digital transformation in these projects remains at an early stage, particularly with respect to social dimensions, which remain underdeveloped. The main contribution of this paper is to provide empirical evidence on the digital transformation process in less industrialized construction contexts, highlighting the role of sociotechnical approaches, Lean Construction, and BIM as key enablers of effective and inclusive digitalization.

KEYWORDS

Digital transformation, construction, lean construction, BIM, sociotechnical approaches.

INTRODUCTION

The construction industry has gone through different revolutions, which can be summarized in 4 main stages: Stage 1, with the employment of crude tools, such as shovels, excavators, and hoes; stage 2, with the use of machines, such as backhoe loaders, loaders, and cranes; stage 3, with the use of Software driven by advances in information technology, and stage 4, named as Construction 4.0 (CR 4.0), using technologies such as cyber-physical systems (Osunsanmi et al., 2020). The concept of Construction 4.0 is typically driven by Industry 4.0 (IR 4.0) technologies and encompasses digitization, digitalization, and automation across multiple stages of construction (Osunsanmi et al., 2020; Adepoju & Aigbavboa, 2020; Lekan et al., 2020). The emergence of Industry 4.0 in construction seeks to transform the sector toward digitally developed businesses (Alaoul et al., 2018). Thus, digitalization is revolutionizing the planning, design, construction, operation, and maintenance of structures (Ozturk, 2021).

More recently, González et al. (2022) introduced the concept of Lean Construction 4.0, defined as a Process-People-Technology Functional Model. This approach is based on the premise that Lean Thinking can serve as a stepping-stone to the effective adoption of Industry 4.0 in construction. From this perspective, Industry 4.0 technologies have the potential to eliminate or reduce the seven Lean wastes originally identified by Shingo et al. (2005) and

[1] Assistant Professor, Department of Civil and Environmental Engineering, Federal University of Paraiba, João Pessoa, Brazil, luara.fernandes@ct.ufpb.br, orcid.org/0000-0003-4041-8025

[2] Associate Professor, School of Engineering, Department of Structural and Construction Engineering, Federal University of Bahia, Salvador, Brazil, dayanabcosta@ufba.br, orcid.org/0000-0002-1457-6401

Taiichi (1988), while Lean Thinking supports waste elimination and value creation, thereby contributing to robust and efficient Industry 4.0 development and implementation. Although Lean Construction 4.0 applications remain in their early stages, this concept offers synergies with the emerging Industry 5.0 (IR 5.0) paradigm (Noueihed & Hamzeh, 2022).

In response to these advances, the Brazilian construction industry has been undergoing a digital transformation, supported by government actions that promote the diffusion of BIM, though progress remains incremental. Since 2017, the Brazilian state has issued several public policies that recognize Building Information Modeling (BIM) as a key enabler of digital transformation in construction. The release of Decree No. 9,833/2018, which launched the first Brazilian BIM Strategy (BIM BR Strategy), marked a milestone in this process, aiming to foster an environment conducive to nationwide BIM adoption and diffusion. Subsequent regulatory advances, including Decree No. 10,306/2020, which established the mandatory use of BIM in some federal spheres, and Law No. 14,133/2021, which introduced the preferential use of BIM in public procurement. In 2024, the BIM BR Strategy was updated by Decree No. 11,888/2024, which expanded its governance structure to include, among others, the Ministry of Education, thereby reinforcing the importance of education and capacity building for digital transformation. These initiatives align with broader national programs, such as Construa Brasil, that aim to modernize the construction industry and increase its productivity and competitiveness.

The literature on theoretical studies of Industry 4.0 and Industry 5.0 in construction and on their implementation in developed regions has advanced rapidly. However, a gap remains in understanding how digital transformation is occurring in the construction industry of less industrialized countries, particularly with respect to the principles of IR 4.0 and IR 5.0. According to Hines et al. (2025), there is also a need to identify DT requirements at the production level.

Therefore, the purpose of the study is to discuss the digital transformation process in construction, drawing on evidence from Brazil. To this end, the Maturity Measurement System (MMS) proposed by Fernandes et al. (2026) was applied to six case studies. The MMS assesses digital transformation maturity in construction production using a sociotechnical approach that integrates principles of Industry 4.0 and Industry 5.0.

THE CONCEPT OF AN INTELLIGENT CONSTRUCTION ENVIRONMENT

Digital Transformation (DT) refers to organizational, operational, and cultural changes in businesses, industries, or ecosystems resulting from the integration of digital technologies, techniques, competencies, and processes, and is commonly portrayed as driven by Industry 4.0 (IR 4.0) concepts and technologies (Shalini & Devi, 2022; Zomer et al., 2019). However, from technological and organizational standpoints, the obstacles to introducing Industry 4.0 lead to rethinking its deficiencies, which include an excessive focus on technology, a lack of resilience, and a weak sustainability model (Zizic et al., 2022; Sindwani et al., 2022; Olah et al., 2020). In response to these limitations, Industry 5.0 (IR 5.) emerges as a shift in perspective in which IR 4.0 technologies are now designed and used to serve people and societies, meeting the needs of industry workers (Noueihed & Hamzeh, 2022). Digital transformation in Industry 5.0 structures enterprises, supply chains, and stakeholder networks while drawing on technological advances, many of which originated in the Third Industrial Revolution and became widely accessible and scalable during IR 4.0 (Saniuk et al., 2022; Gobakhloo et al., 2022). For Fernandes and Costa (2024), digital transformation in construction must be driven by both IR 4.0 and IR 5.0 principles.

Furthermore, Bednar and Welch (2019) propose a contemporary sociotechnical perspective for approaching work environments in Industries 4.0 and 5.0, emphasizing the uncertainty and complexity inherent in processes of technological change (Sawyer & Jarrahi, 2015). In line with

this perspective, a sociotechnical approach is especially valuable, as it not only highlights the smaller components within a complex environment but also enables a deeper understanding of the interconnected elements involved in generating, collecting, processing, and using information, thereby transcending the technological dimension.

In this context, Fernandes and Costa (2024) proposed the concept of an Intelligent Construction Environment for digital transformation during the construction phase, adopting a sociotechnical approach based on the principles of the last two industrial revolutions. According to these authors, an Intelligent Construction Environment is an efficient, resilient, human-centered, and sustainable environment composed of a complex sociotechnical system that uses digital technologies as tools to support continuous improvement. Its elements dynamically interact to achieve the principles of digital transformation in construction, which are: Human centricity, Flexibility, Resilience, Transparency, Collaboration, Decentralization, Virtualization, Horizontal and vertical integration, Timely capability, Sustainable management, Predictive capacity, and Interoperability (Fernandes & Costa, 2024). This complex sociotechnical system comprises three subsystems (Social, Technical, and Operational) and six elements (Human Resources, Culture, Digital Technologies, Work Infrastructure, Production Processes, and Performance).

RESEARCH METHOD

This study adopts a multiple-case study research strategy. This empirical approach supports the analysis of a contemporary phenomenon in its real-life context, especially when the boundaries between the phenomenon and its context are not clearly defined (Yin, 2001). This strategy is well-suited to the present research because it enables in-depth investigation while preserving the holistic and meaningful characteristics of real-life events, drawing on multiple sources of evidence that converge through triangulation (Yin, 2001).

The tool used to assess the projects was the Maturity Measurement System for an Intelligent Construction Environment (MMS), proposed by Fernandes et al. (2026) (Figure 1). The MMS comprises 15 social, technical, and operational indicators, structured into 75 assessment criteria distributed across five maturity levels.

The system evaluates the critical aspects (dimensions) of an intelligent construction environment that must be managed to achieve the principles of digital transformation in construction. These dimensions are organized into three interrelated subsystems and include: Training, Communication, Occupational Health and Safety, Coordination, Sustainability, Innovation, Quality Management, Performance Management, Cost Management, Complexity Management, Production Planning and Control, Storage and Logistics Management, Timely Decision-Making, Technology Implementation and Management, Development of Digital Solutions, Collection, Storage, Processing, Analysis, and Management of Massive and Complex Data, Data Security, Construction Site Layout, and Workspace.

Each dimension is operationalized through a set of specific assessment criteria, which are evaluated on a scale from 0 (not achieved) to 4 (fully achieved). The scores obtained for these criteria are aggregated to calculate a maturity indicator for each dimension. Subsequently, dimension-level indicators are consolidated to determine maturity levels within each subsystem and the overall maturity of the construction environment. Therefore, the maturity assessment is conducted procedurally across three scopes: Overall Maturity, Subsystem Maturity, and Dimension Maturity. The MMS has five maturity levels: Enabling (0), Initializing (1), Embedding (2), Integrating (3), and Continuously Improving (4). The tool can be accessed via the following link (OMITTED FOR REVIEW).

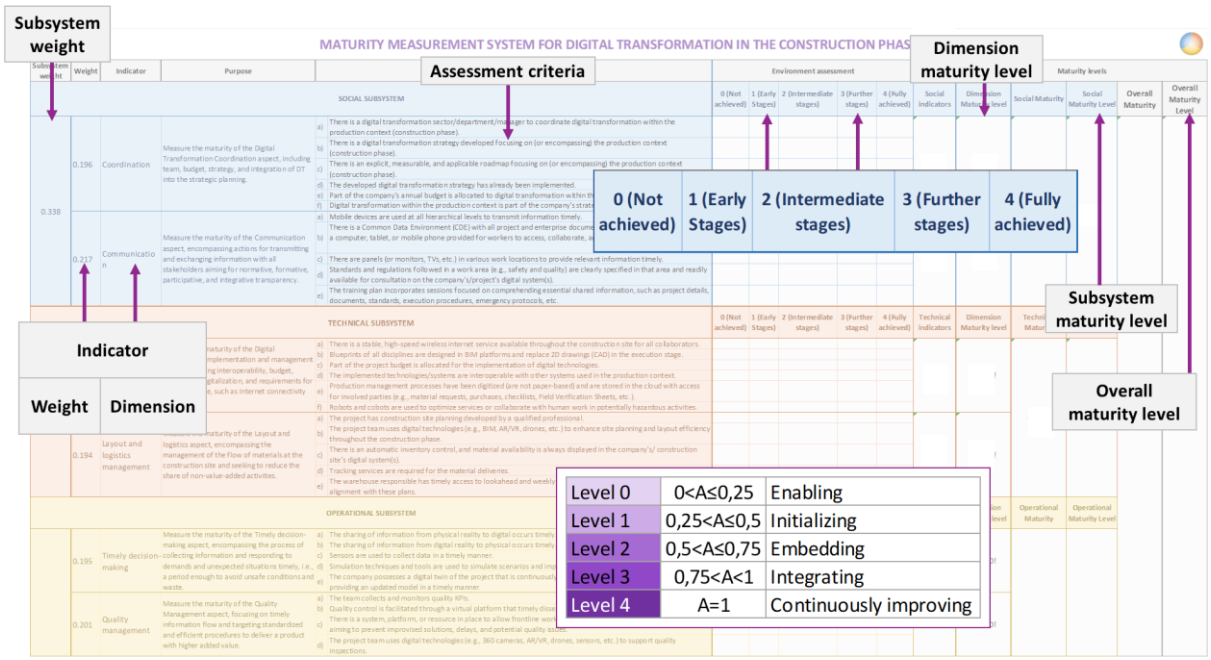

Figure 1: Structure of the maturity measurement system (adapted from Fernandes et al., 2026)

The MMS was applied to six construction projects (Table 1) between June and August 2024, with each site visit lasting approximately four hours. The evaluation drew on multiple sources of evidence, including documents, unstructured interviews, direct observations, photographs and videos, questionnaires, training materials, planning and control worksheets, Power BI dashboards, and project documentation. Each visit was conducted by the researchers and a member of the construction site management team, who provided the material to assess each indicator and indicated workers able to respond to questions.

Table 1: Characterization of the studied construction projects

Project	Location	Date of Application	Company Size	Project Type	Number of Towers	Predominant Construction System	Company Considers Itself in a Digital Transformation Process
C1	Salvador-BA	6/13/2024	Large-scale	High-end	2	Cast-in-place reinforced concrete	Yes
C2	Salvador-BA	6/17/2024	Mid-sized	High-end	1	Cast-in-place reinforced concrete	Yes
C3	Salvador-BA	6/18/2024	Multinational	Social Housing	5	Cast-in-place concrete wall	Yes
C4	Salvador-BA	6/18/2024	Small-sized	High-end	1	Cast-in-place reinforced concrete	No
C5	João Pessoa-PB	8/1/2024	Mid-sized	High-end	1	Cast-in-place reinforced concrete	No
C6	João Pessoa-PB	8/8/2024	Small-sized	Mid-range	1	Cast-in-place reinforced concrete	Yes

RESULTS AND DISCUSSION

OVERALL MATURITY

The assessment revealed overall maturity levels ranging from Level 0 (Enabling) to Level 2 (Embedding), as shown in Table 2. Projects C4 and C6 were classified as Enabling, the lowest maturity level. These projects showed a pronounced lack of coordination and training initiatives, an absence of strategic actions, and Enabling-level (Level 0) performance across all technical dimensions. In Project C6, approximately 40% of the assessed dimensions were classified as having no requirements, scoring 0 (not achieved) across all evaluation criteria. This finding suggests substantial deficiencies in its digital transformation capabilities. As a result, Projects C4 and C6 demonstrated the weakest performance in all evaluated subsystems.

Table 2: Summary of overall maturity results

Project	Overall Maturity	Overall Maturity Level
C1	0,446	Initializing
C2	0,323	Initializing
C3	0,528	Embedding
C4	0,179	Enabling
C5	0,275	Initializing
C6	0,11	Enabling

Legend (Maturity levels):

Level 0	Enabling	1	Initializing	2	Embedding	3	Integrating	4	Continuously improving

Projects C1, C2, and C5 reached the Initializing level, indicating early-stage progress toward digital transformation. Among them, C1 demonstrated the most balanced development, with all subsystems at the Initializing level and approximately one-third of its dimensions achieving the Embedding level. Although C2 was classified overall at the Initializing level (Level 1), it scored at the Enabling level (Level 0) in both the Social and Technical subsystems. This resulted in an overall maturity score of 0.275, placing it very close to the Enabling (Level 0) threshold and suggesting a highly embryonic and unbalanced digital transformation process.

Project C3 demonstrated the highest performance, achieving Level 2 (Embedding) maturity. Nearly 47% of its assessed dimensions were classified at the Embedding (Level 2) or Integrating (Level 3) levels, indicating a more advanced approach to digital transformation leadership and a broader adoption of digital technologies. Project C3 reached the Embedding (Level 2) stage in both the Social and Technical subsystems. However, its Operational subsystem remained at Initializing (Level 1), reflecting ongoing challenges in extending digital technologies to the construction site and integrating them effectively into production activities, as detailed below.

None of the assessed projects reached the Integrating (Level 3) or Continuously Improving (Level 4) levels of overall maturity. Table 2 summarizes the overall maturity results.

SUBSYSTEM MATURITY

Among the projects, C3 achieved the strongest performance in the Social subsystem, scoring 0.560 and reaching the Embedding level (Level 2). This performance is likely supported by the fact that they have established a dedicated unit to drive digital transformation. Project C1 also demonstrated relatively strong performance, with a score of 0.429. However, it remained within the Initializing level due to a score of 0.00 in the Coordination dimension. In contrast, Project C6 recorded the lowest performance in this subsystem, with four of five dimensions scoring 0.00.

In the Technical subsystem, most projects performed slightly better than in the Social one. Project C3 demonstrated the strongest performance, with a score of 0.525, corresponding to the Embedding level (Level 2), and reflecting substantial development of innovative solutions and the implementation of digital technologies. Projects C1 (0.469) and C2 (0.371) were classified at Level 1 (Initializing), with C1 showing progress toward Level 2. In contrast, Projects C4, C5, and C6 remained at the Enabling level, presenting very limited application of digital technologies in the production phase.

Regarding the Operational subsystem, most projects were assessed at Level 1 (Initializing), whereas Project C6 remained at Level 0 (Enabling). Although Project C3 achieved the highest score in this subsystem (0.498), it still fell within Level 1. This outcome is expected, as digital technologies are not yet being effectively implemented or incorporated into routine production activities. As the Operational subsystem directly reflects on-site production practices, its maturity is more strongly affected by the extent to which digital solutions are embedded in daily workflows.

At the strategic level, the C3 organization has articulated clear objectives for digital transformation, including the implementation of digital technologies, the establishment of partnerships with universities and research centers to develop digital solutions, and substantial financial investments (approximately US$50 million over the past five years) to support these initiatives. These efforts are reflected in the comparatively stronger performance observed in the Social and Technical subsystems. Nevertheless, the application of digital technologies within the production environment remains punctual and fragmented, limiting their operational effectiveness. In addition, training initiatives are not adequately reaching frontline workers, resulting in weak integration of digital tools due to insufficient workforce preparedness. Overall, digital transformation efforts have not yet been effectively extended to the production environment and, consequently, have not become embedded in day-to-day construction practices. Table 3 summarizes the results of subsystem maturity.

Table 3: Summary of subsystem maturity results

Project	Social		Technical		Operational	
C1	0,429	Initializing	0,469	Initializing	0,441	Initializing
C2	0,117	Enabling	0,371	Initializing	0,485	Initializing
C3	0,56	Embedding	0,525	Embedding	0,498	Initializing
C4	0,103	Enabling	0,177	Enabling	0,257	Initializing
C5	0,21	Enabling	0,239	Enabling	0,378	Initializing
C6	0,011	Enabling	0,157	Enabling	0,165	Enabling

Legend (Maturity levels):

Level 0	Enabling	1	Initializing	2	Embedding	3	Integrating	4	Continuously improving

DIMENSIONS MATURITY

Table 4 presents the maturity assessment of the dimensions for the six studied projects. The overall distribution shows that most dimensions have low levels of maturity: 11% are at No requirements, 42% at Enabling (Level 0), 27% at Initializing (Level 1), 17% at Embedding (Level 2), and only 3.3% at Integrating (Level 3), with no dimensions reaching Continuously Improving (Level 4).

The Social dimensions present the largest number of No requirements, accounting for 80% of all cases in this category, indicating that no criteria (0.00 score) were met in those dimensions. “Coordination” and “Training” had no criteria met in half of the studied projects, suggesting the absence of a coordinated approach to digital transformation. This suggests a lack of clear digital transformation strategies and insufficient workforce inclusion in the process, leading to

isolated digital technology implementations and actions that are not aligned with the company's strategic planning. No Social dimensions in any of the projects achieved the levels Integrating (Level 3) or Continuously Improving (Level 4).

The analysis of the Technical dimensions revealed that 87% of the evaluations were classified as Enabling (Level 0) or Initializing (Level 1). Only three dimensions reached the Embedding level (Level 2): "Development of innovative solutions" in Project C2, and "Layout and logistics management" in Projects C1 and C3. Among all technical dimensions, "Development of innovative solutions" was the only one to achieve the Integrating level (Level 3), representing the highest score of this pilot study. No Technical dimensions across the projects reached the Continuously Improving level (Level 4), and none recorded a score of 0.00.

Some operational dimensions showed comparatively better performance, with 23% of the assessments reaching the Embedding stage (Level 2). Among these, "Quality management" reached this level in three projects (C1, C4, and C5), while "Production planning and control" and "Complexity management" did so in two projects (C2 and C5). In addition, "Complexity management" and "Performance management" reached the Integrating stage (Level 3) in Projects C2 and C3, respectively, representing the highest scores observed among the operational dimensions. No dimension reached the Continuously Improving stage (Level 4). Project C6 recorded a score of 0.00, with no criteria met in "Timely decision-making" and "Quality management."

It is worth noting that "Timely decision-making" performed the worst among all operational dimensions, with five projects classified at the Enabling stage (Level 0) and C6 showing No Requirements. As Timely decision-making is a core capability of digitally transformed environments, its consistently low performance indicates limited use of real-time (or timely) data and analytics to support operational decisions, representing a critical constraint to the effective operationalization of digital transformation.

Table 4: Summary of dimension maturity results

Subsystem	Dimensions / Indicator e maturity level	Dimension maturity assessment											
		C1		C2		C3		C4		C5		C6	
Social	Coordination	0,000	No requirements	0,083	Enabling	0,393	Initializing	0,000	No requirements	0,042	Enabling	0,000	No requirements
	Sustainability	0,600	Embedding	0,200	Enabling	0,700	Embedding	0,200	Enabling	0,050	Enabling	0,000	No requirements
	Training	0,400	Initializing	0,000	No requirements	0,450	Initializing	0,000	No requirements	0,400	Initializing	0,000	No requirements
	Communication	0,500	Initializing	0,200	Enabling	0,700	Embedding	0,167	Enabling	0,200	Enabling	0,050	Enabling
	Occupational safety	0,650	Embedding	0,100	Enabling	0,550	Embedding	0,150	Enabling	0,350	Initializing	0,000	No requirements
	Technology implementation and management	0,250	Enabling	0,250	Enabling	0,250	Enabling	0,208	Enabling	0,292	Initializing	0,083	Enabling
	Development of innovative solutions	0,450	Initializing	0,650	Embedding	0,850	Integrating	0,100	Enabling	0,100	Enabling	0,050	Enabling
Technical	Collection, storage, processing, analysis, management, and security of massive and complex data	0,500	Initializing	0,313	Initializing	0,450	Initializing	0,250	Enabling	0,250	Enabling	0,200	Enabling
	Layout and logistics management	0,650	Embedding	0,400	Initializing	0,650	Embedding	0,200	Enabling	0,300	Initializing	0,200	Enabling
	Workspace	0,500	Initializing	0,250	Enabling	0,438	Initializing	0,125	Enabling	0,250	Enabling	0,250	Enabling

Legend (Maturity levels):

Level 0	Enabling	1	Initializing	2	Embedding	3	Integrating	4	Continuously improving

Table 4: Summary of dimension maturity results (continued)

Subsystem	Dimensions / Indicator e maturity level	Dimension maturity assessment											
		C1		C2		C3		C4		C5		C6	
Operational	Complexity management	0,550	Embedding	0,800	Integrating	0,650	Embedding	0,050	Enabling	0,350	Initializing	0,250	Enabling
	Production planning and control	0,350	Initializing	0,700	Embedding	0,500	Initializing	0,400	Initializing	0,600	Embedding	0,500	Initializing
	Timely decision-making	0,250	Enabling	0,100	Enabling	0,100	Enabling	0,100	Enabling	0,100	Enabling	0,000	No requirements
	Quality management	0,563	Embedding	0,313	Initializing	0,438	Initializing	0,563	Embedding	0,563	Embedding	0,000	No requirements
	Performance management	0,500	Initializing	0,500	Initializing	0,800	Integrating	0,150	Enabling	0,250	Enabling	0,050	Enabling

Legend (Maturity levels):

Level 0	Enabling	1	Initializing	2	Embedding	3	Integrating	4	Continuously improving

CONTEXTUALIZATION OF THE RESULTS WITHIN THE LITERATURE AND LOCAL CONTEXT

The results of the maturity assessment indicate that the analyzed projects remain in the early stages of digital transformation. Although differences exist among the six construction projects, none demonstrates a consolidated level of digital maturity in the construction phase. This suggests that digital transformation in construction is still incipient and unevenly implemented at the production level. The findings further indicate that low digital maturity is more strongly associated with social aspects than with a lack of technological investment. This is illustrated by Project C3, which, despite investments of approximately US$50 million, continues to face challenges in effectively integrating digital tools into production activities. These results indicate that financial investment and technology adoption alone are insufficient to achieve digital transformation when organizational and cultural conditions are not properly addressed.

Given this scenario, Lean Construction emerges as a key enabler of digital transformation in the construction industry. Lean thinking emphasizes eliminating waste and creating value by focusing on people, collaboration, standardization, continuous improvement, and respect for workers, thereby providing a structured approach to address the social gaps identified in the maturity assessment. Several studies highlight an important synergy between Lean Construction and Industry 4.0. Hossain and Purdy (2025) identify a positive association between Lean and Industry 4.0, while Fang et al. (2025) argue that integrating Industry 4.0 technologies with Lean Construction ambidexterity enables firms to navigate complex, dynamic project environments more effectively, while simultaneously advancing economic, environmental, and social sustainability. Thus, Dallasega et al. (2018) emphasize that effective implementation of Industry 4.0 in construction supply chains requires appropriate management strategies, which may reinforce Lean's role as a managerial and strategic foundation for digitalization. Therefore, Lean Construction may support digital transformation by enabling process redesign and management alignment, and by guiding technology implementation informed by efficient, collaborative, and people-centered practices rather than by implementing technology in isolation.

Moreover, the integration of Lean Construction and BIM further illustrates this enabling role. When jointly implemented during the design phase, the Lean-BIM approach enhances efficiency, fosters collaboration, and improves overall project performance (Mounla et al., 2025). Polat and Demirkesen (2025) argue that Lean directly supports BIM adoption by “cleaning” processes prior to digitalization. Practices such as process standardization help prevent rework in BIM workflows (Polat & Demirkesen, 2025). At the same time, tools such as the 5 Whys support the identification and elimination of root causes and encourage interdisciplinary collaboration, which is central to BIM-based processes (Polat & Demirkesen, 2025).

Furthermore, Lean Construction is closely aligned with the human-centered perspective of Industry 5.0. Mladineo et al. (2021) show that most key success factors for Lean management and tool implementation in SMEs are people-oriented, reflecting the human-centric approach promoted by Industry 5.0. Consistently, Solaimani and Sedighi (2020) demonstrate that Lean Construction positively impacts all three pillars of sustainability in construction projects. Gdoura et al. (2025) argue that integrating Lean requirements into an Industry 5.0 context during the design phase is an effective strategy to enhance the overall performance of construction environments.

Another important insight that emerged from applying the MMS is that, throughout the assessment process, managers demonstrated an increasing awareness of the need for digital transformation. This awareness appears to be closely driven by institutional actions, such as BIM decrees, the Construa Brasil Program, and the new Brazilian public procurement law.

These initiatives have positioned BIM as a mandatory or strategic requirement, encouraging companies to initiate their digitalization efforts. These findings may suggest that the current institutional push for BIM implementation is contributing to the reduction of cultural barriers to technology adoption that have traditionally characterized the construction sector. Increased exposure to BIM concepts, practices, and regulatory requirements appears to be weakening this resistance, which Fernandes and Costa (2022) identified as a key obstacle to digital transformation in construction. In this context, BIM can be understood as a gateway to Construction 4.0, as it consolidates project information within a shared digital environment and enables data integration and collaboration among multiple stakeholders.

Another important topic of discussion concerns the role of industrialization in Construction 4.0. Previous studies have highlighted industrialization as one of the core pillars of CR 4.0. For example, Forcael et al. (2020) argue that Construction 4.0 is fundamentally supported by the digitalization of the construction sector and the industrialization of construction processes. However, this perspective largely reflects a direct transposition of Industry 4.0 and Industry 5.0 concepts developed for highly industrialized sectors, such as manufacturing, automotive, and chemical industries. When applied to construction, especially in less industrialized countries, this perspective presents important limitations. Construction in these contexts remains highly craft-based, strongly dependent on human labor, and characterized by complex, dynamic, and fragmented construction sites. A significant portion of construction projects still relies on traditional construction systems, characterized by high variability, manual labor, and low levels of standardization. In this context, restricting digital transformation initiatives to highly industrialized construction environments may exclude many organizations from the benefits of digitalization. It is important to emphasize that industrialization in construction should not be disregarded or opposed. Rather, it represents a strategic objective for improving productivity, quality, and sustainability in the construction industry and should be actively encouraged. National initiatives such as the Construa Brasil Program explicitly reinforce this perspective by positioning digitalization and industrialization as complementary and strategic goals for sector development.

Although digitalization and industrialization are mutually reinforcing processes (since digital technologies can enable more efficient industrialized systems, and industrialization can facilitate the adoption of digital tools), it is essential to acknowledge the current reality of the construction industry in less industrialized countries. In these contexts, construction practices remain largely traditional, highlighting the need to understand how organizations can initiate and advance digital transformation without relying on high levels of industrialization. In this scenario, sociotechnical approaches, such as the MMS, become especially relevant, as they support this process by enabling a structured understanding of how information is generated, collected, processed, and used across interconnected elements that extend beyond purely technological considerations. By providing a framework for modeling and analyzing complex systems (Oosthuizen & Pretorius, 2016), these approaches offer a robust foundation for supporting digital transformation in construction contexts characterized by low levels of industrialization.

CONCLUSION

This study aimed to discuss the digital transformation (DT) process in less industrialized countries, providing evidence from the Brazilian construction industry. For that, the Maturity Measurement System (MMS) proposed by Fernandes et al. (2026) was applied to six case studies to assess DT maturity in construction production, using a sociotechnical approach that integrates Industry 4.0 and Industry 5.0 principles. Results suggest that DT implementation in the analyzed projects remains at an early stage. Three projects were classified at the Initializing level, one at the Embedding level, and two at the Enabling level. In terms of dimensions, the

Social dimensions present the largest number of "No requirements", and none of the projects achieved the Integrating or Continuously Improving levels. The analysis of the Technical dimensions revealed that 87% of the evaluations were classified as Enabling or Initializing. Some Operational dimensions showed comparatively better performance, with 23% of the assessments reaching the Embedding level.

Findings also indicate that Lean Construction can be a foundation for digitalization, supporting process redesign, value creation, management alignment, and the implementation of people-centered technologies. Additionally, the data collected in this study suggest that public policies related to BIM in Brazil have contributed to raising awareness and reducing cultural barriers to DT, positioning BIM as a potential gateway to Construction 4.0. The main contribution of this paper is to provide empirical evidence on the digital transformation process in less industrialized construction contexts, highlighting the role of sociotechnical approaches, Lean Construction, and BIM as enablers for effective and inclusive digitalization.

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