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Digital technologies in construction companies: case studies in the context of construction 4.0

Girlândia de Morais Sampaio
Master's student, UPE, Brasil
gms8@poli.br

Emanoel Silva de Amorim
Master Researcher, UPE, Brasil
esa7@poli.br

Alberto Casado Lordsleem Júnior
Professor Doctor, UPE, Brasil.
acasado@poli.br

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ABSTRACT

Industry 4.0's main function is to provide savings, agility and competitive advantage, through innovative solutions, when its concepts and principles are applied to the construction sector, it is referred to as "Construction 4.0". The digital technologies that constitute construction 4.0 can be introduced in all areas of the construction industry with the global objective of increasing productivity and, at the same time, simplifying work and reducing errors. In this sense, the present work aimed to identify the main challenges and actions necessary for implementation of digital technologies by construction companies in the context of the changes that guide technological advances in digital transformation. To this end, the methodology adopted included literature research, which sought to embroider important concepts, characteristics and classifications on the principles of industry 4.0 and the use of digital technologies in construction companies, followed by case studies carried out in construction companies in the city from Recife-PE involved in actions aimed at digital transformation. The results present the main digital technologies used in construction companies as well as the sectors suitable for their respective implementations. Furthermore, it was concluded that the adoption of digital technologies is crucial for digital transformation in construction companies; however, the costs associated with the development and adoption of new digital technologies, as well as customer conservatism, represent the biggest barriers to implementation in construction companies. The main contribution is the presentation of guidelines for implementing digital technologies in construction companies.

KEYWORDS: Digital Technologies. Construction 4.0. Digital Transformation. BIM.

Tecnologias digitais em empresas construtoras: estudos de caso no contexto da construção 4.0

RESUMO

A Indústria 4.0 tem como principal função proporcionar economia, agilidade e vantagem competitiva, através de soluções inovadoras, quando seus conceitos e princípios são aplicados ao setor da construção, refere-se a eles como "Construção 4.0". As tecnologias digitais que constituem a construção 4.0 podem ser introduzidas em todas as áreas da indústria da construção com o objetivo global de aumentar a produtividade e, ao mesmo tempo, simplificar o trabalho e reduzir erros. Nesse sentido, o presente trabalho objetivou identificar os principais desafios e ações necessárias para a implementação de tecnologias digitais pelas empresas construtoras no contexto das mudanças que orientam os avanços tecnológicos da transformação digital. Para tanto, a metodologia adotada contemplou a realização de pesquisa da literatura, a qual buscou bordados conceitos, características e classificações importantes sobre princípios da indústria 4.0 e o uso de tecnologias digitais em empresas construtoras, seguida de estudo de casos realizado em empresas construtoras da cidade de Recife-PE envolvidas em ações voltadas à transformação digital. Os resultados apresentam as principais tecnologias digitais usadas em empresas construtoras bem com os setores adequados para suas respectivas implementações. Além disso concluiu-se que a adoção de tecnologias digitais é crucial para a transformação digital em empresas construtoras; contudo, os custos associados ao desenvolvimento e adoção de novas tecnologias digitais, bem como o conservadorismo de clientes, representam as maiores barreiras para implementação em empresas construtoras. Como principal contribuição, tem-se a apresentação de diretrizes para implementação de tecnologias digitais em empresas construtoras.

PALAVRAS-CHAVE: Tecnologias Digitais. Construção 4.0. Transformação Digital. BIM.

Tecnologías digitales en las empresas constructoras: estudios de caso en el contexto de la construcción 4.0

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RESUMEN

La principal función de la Industria 4.0 es brindar ahorro, agilidad y ventaja competitiva, a través de soluciones innovadoras, cuando sus conceptos y principios se aplican al sector de la construcción, se le denomina “Construcción 4.0”. Las tecnologías digitales que constituyen la construcción 4.0 pueden introducirse en todos los ámbitos de la industria de la construcción con el objetivo global de aumentar la productividad y, al mismo tiempo, simplificar el trabajo y reducir errores. En este sentido, el presente trabajo tuvo como objetivo identificar los principales desafíos y acciones necesarias para la implementación de tecnologías digitales. por las empresas constructoras en el contexto de los cambios que guían los avances tecnológicos en la transformación digital. Para ello, la metodología adoptada incluyó una investigación bibliográfica, que buscó bordar importantes conceptos, características y clasificaciones sobre los principios de la industria 4.0 y el uso de tecnologías digitales en las empresas constructoras, seguida de estudios de caso realizados en empresas constructoras de la ciudad de Recife-PE participa en acciones orientadas a la transformación digital. Los resultados presentan las principales tecnologías digitales utilizadas en las empresas constructoras, así como los sectores aptos para sus respectivas implementaciones. Además, se concluyó que la adopción de tecnologías digitales es crucial para la transformación digital en las empresas constructoras; sin embargo, los costos asociados con el desarrollo y la adopción de nuevas tecnologías digitales, así como el conservadurismo del cliente, representan las mayores barreras para la implementación en las empresas constructoras. El principal aporte es la presentación de lineamientos para la implementación de tecnologías digitales en las empresas constructoras.

PALABRAS CLAVE: Tecnologías digitales. Construcción 4.0. Transformación Digital. BIM.

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1 INTRODUCTION

Characterized as one of the largest industries in the world, the construction sector drives global economic growth and is one of the sectors that contributes most to job creation. The Brazilian Chamber of the Construction Industry (CBIC) has presented forecasts indicating that the construction sector will continue to play a crucial role in modernization and improvement of practices, including the introduction of innovations and technological evolution (CBIC, 2024).

The world is witnessing technological advancements across various industry sectors, and construction is no exception. Constantly, new machines, software, and technologies are developed to support management, aiming to reduce errors in project planning, from the physical process involving its duration to the financial process related to cost forecasting for the project (Silva *et al.,* 2019). According to Guimarães and Santos (2022), the construction sector holds significant importance in the global industry landscape and is undergoing constant transformations. Additionally, companies are increasingly seeking alternatives that provide competitive advantages, resource savings, and continuous improvements, offering flexibility to quickly adapt to market changes (Guimarães; Santos, 2022).

According to Craveiro et al. (2019), some industrial sectors, such as automotive and aerospace, have undergone changes by adopting digital technologies to improve quality and productivity. This transformation is described as Industry 4.0, which is transforming both industrial and production value chains and the business models of companies. In Construction 4.0, the application of Industry 4.0 concepts, philosophy, and principles is aligned with the construction industry (Berger, 2016; Sawhney *et al.*, 2020).

In the face of technological innovations and constant changes, the work activities of a construction company need to focus on the use of digital technologies for planning, budgeting, project sales, execution, and administration processes, bringing benefits to the company (Kozlovska; Klosova; Strukova, 2021).

A study by the McKinsey Institute (2019) indicates that companies in the engineering and construction sector continue to face difficulties in implementing a digital transformation program at scale. Attempts to streamline projects with digital solutions have been frustrated, making this sector one of the least digitalized in the world. These challenges complicate the development of replicable digital solutions for other engineering and construction projects.

The primary objective of adopting digital technologies in the construction industry is to modernize operations, ensuring cost and time savings, increased production, and a customer-centric work model. The success of digital transformation in the construction industry largely depends on cultural transformation, and mobilizing the people involved is crucial for the success of digitalization initiatives in construction.

Therefore, it is essential to deepen the understanding of the applicability of digital technologies, aiming for productivity and efficiency, and promoting best practices in the construction industry.

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This research aimed to study the digital transformation process in construction companies in the city of Recife, to understand the strategies and mechanisms adopted for the implementation of digital technologies and the challenges faced in the process. The primary objective was to identify, systematize, and document knowledge about digital technologies to structure best practices applicable to construction companies.

2 OBJECTIVE

The present objective was to understand the strategy and mechanisms adopted for the implementation of digital technologies and the challenges faced in the process. The main objective was to identify, systematize and record knowledge about digital technologies with the aim of structuring best practices applied to construction companies.

3 LITERATURE REVIEW

Digital transformation in an organization can occur through the use of new technologies and the participation of the network of involved collaborators, including information, computing, communication, and connectivity technologies. In the digital transformation process, it is the company that changes - but such changes only happen after innovation. This means that digital transformation alters the pillars on which the company is founded, involving profound changes in the way of thinking and dealing with new technologies (Vial, 2019; Schallmo *et al.*, 2017).

As digital transformation progresses within organizations, literature has introduced models capable of assessing the levels of maturity associated with digital transformation practices. Table 1 below presents the main maturity models related to digital transformation.

- *Capability Maturity Model* – CMM: Created by the Software Engineering Institute (SEI) at Carnegie Mellon University / 1991, with a secure structure designed to help organizations assess the maturity of their software processes. With the objective of improving and optimizing software development and maintenance processes in organizations. Presenting four levels: Initial, Repeatable, Defined, Managed and Optimized.
- European Foundation for Quality Management (EFQM) Excellence Model: Launched by the European Foundation for Quality Management / 1992. It presents a management framework that helps organizations manage change and improve performance with three levels: Direction, Execution and Results.
- *Kerzner Project Management Maturity Model* – KPM3: created by Harold Kerzner / 2001. Presents strategic management and project management plans for any organization and five levels of language: Common, Common Processes, Singular Methodology, Benchmarking and Continuous Improvement.

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- *Project Management Maturity Model* – PMMM: created based on existing business models, such as CMM and EFQM. With the aim of improving project management processes for any organization, it has five levels: Initial process, Structured process and standards, Institutionalized process, Managed process and Optimization process.
- *Organizational Project Management Maturity Model* - OPM3: Published by the Project Management Institute (PMI) / 2003. Aiming to understand and evaluate an organization's ability to implement its high-level strategic planning, managing its portfolio, and then assist in educating project management professionals and laypeople on the influential effects of applying project management principles in the following steps: Standardize, Measure, and Control.
- *Portfolio, Programme and Project Management Maturity Model* - P3M3: Released by the Office of Government Commerce (OGC) / 2006. A best practice tool for the constituent domains of organizational project management, including portfolio management, program management, and project management. Used in corporate, public sector, government, and non-profit organizations of all sizes and across a variety of industries. Featuring five levels: Process Awareness, Repeatable Process, Defined Process, Managed Process, and Process Optimization.

3.1 Digital Technologies in Construction 4.0

The implementation of technology can bring significant competitive benefits to the construction industry. Large, medium, and small construction companies consider the use of digital technologies in innovative development as a key factor for success in the competitive construction sector (Hansen; Tatum; 2018).

For a process that involves the use of digital technologies to create or modify business operations, digital transformation is applied. This is defined as a process of structural transformations that integrates the use of digital technology to improve performance, optimize results, and bring about technical changes in various sectors of society. Generally, digital transformation is the conversion of analog processes into digital ones (Ministério da Ciência, Tecnologia e Inovação, 2023).

According to the research titled "Digital Transformation: The Future of Connected Construction," conducted by the International Data Corporation (IDC) with participation from 835 professionals from large construction firms in 12 countries across Europe, the Americas, and Asia, including Brazil, it was found that 72% of construction companies worldwide are prioritizing the topic within their organizations. The study outlined five phases of digital transformation, as described in Figure 1, and also revealed that nearly 60% of companies are in phases one and two, indicating they are only beginning their digital journey (*Internacional Data Corporation*, 2020).

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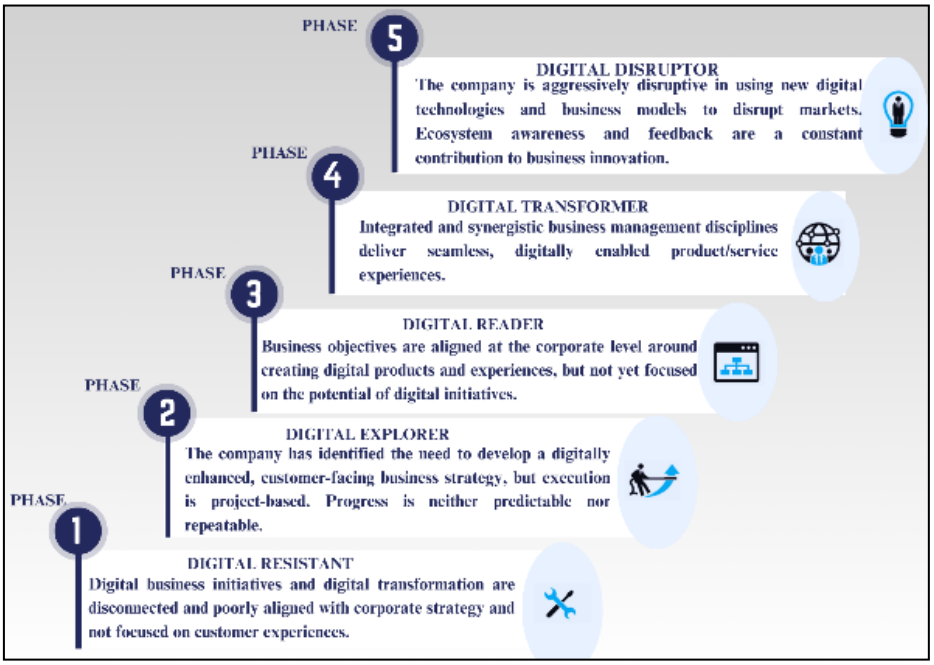
Figure 1: Phases of Digital Transformation



Source: Adapted from IDC (2020)

Digital technologies are defined as a set of tools, methods, and techniques aimed at solving various problems through the transmission of information and data over a relatively short period. The application of digital technologies to enhance productivity in construction is increasingly common in the daily activities of professionals in the construction sector. In this context, investing in technology is essential to enable the development and use of innovative materials and processes, leading to higher quality through efficient projects with reduced costs (MCTI, 2023).

The main digital technologies identified as pillars of Construction 4.0 are briefly described in Table 1.

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Table 1: Main Digital Technologies in Construction 4.0

Tecnology	Source	Definition	Focus	Application
Building Information Modelling – BIM	Crotty, R., 2012. Sacks *et al.*, 2018. Dadashi Haji *et al.*, 2023.	Building Information Modeling (BIM) is not a specific software but rather a working methodology that uses three-dimensional models for project development. It allows for the creation of a virtual model of the construction project, enabling the simulation of all project stages, from conception to execution. This involves professionals in Architecture, Engineering, and Construction working collaboratively on the projects.	BIM modeling creates intelligent virtual components that are closely analogous to real-world physical components, allowing designers to construct the project virtually before it is built in the real world. BIM modeling facilitates communication, data exchange, and protocols, ensuring that systems and teams can effectively interact and collaborate.	• 3D – Three-dimensional modeling • 4D – Planning • 5D – Budgeting • 6D – Sustainability • 7D–Asset management and maintenance • 8D – Site safety • 9D – Lean construction • 10D–Construction industrialization
Big Data	Machado, 2018. Sousa *et al.,* 2020.	Big Data technology focuses on collecting, filtering, and organizing large volumes of information and data. This process is facilitated by specific and integrated solutions that capture and aggregate data in structured or unstructured formats at high speeds. The databases obtained through Big Data technology should be considered one of the most significant advantages for construction companies, as it also interacts with other technologies, feeding management software and 3D modeling programs.	By using Big Data technology in the construction industry, a company can conduct more effective market and process research for the development, execution, and delivery of products and services. The data obtained and utilized helps optimize activity stages, leading to improved results, profitability, and growth through more informed decision-making.	The application of Big Data is divided into five aspects: • Volume, Variety, and Velocity refer to the large amount of unstructured data that the knowledge area can analyze at high speed. • Veracity refers to the sources and quality of the data, which must be reliable. • Value is related to the benefits that the use of Big Data can bring to the company.
Cloud Computing	Neto, 2019. Acquarone *et al.,* 2019	Cloud Computing refers to the on-demand delivery of computing services over the internet. These services include file storage, networking, software, databases, and servers	The main feature of cloud computing is that it eliminates the need to save files and install programs on your own computer. Software and systems are installed on remote servers and can be accessed by any authorized user with an internet connection..	The construction industry also benefits from this technology. For example, in departments responsible for purchasing and accounts payable, it becomes possible to manage purchase orders and vendor payments through integrated and digitally connected management solutions.

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Continuation of Table 2: Main Digital Technologies in Construction 4.0

Internet of Things - IoT	Martins, 2023. Borges; Corrêa, 2022.	Internet of Things (IoT) refers to the connection of everything from small objects to large machines, functioning through sensors to collect data, network connections to transmit data, and data processing typically centralized in software. Users interact with these systems through applications.	Monitoring Machinery, Tracking Material Performance, or Personal Protective Equipment (PPE)	The application of IoT in construction is summarized as the use of devices and equipment (smartphones, computers, or other interfaces) connected through a network to report, modify, and monitor the construction site environment.
Virtual and Augmented Reality	Freitas; Ruschel, 2010	Virtual reality uses equipment to transport the user to a digital world that does not physically exist, creating an immersive experience that makes the user feel as though they are inside that environment. Augmented reality involves combining elements of the real world with virtual elements, enhancing the user's perception of the real world by overlaying digital information onto it.	Observe objects in the physical environment with the aid of augmented reality glasses	Virtual reality and augmented reality technologies can be applied from the project design phase, enhancing visualization of elements and providing an immense level of detail.
Robotics	Portal da indústria, 2023. Gabriel; Amaral; Campos, 2018.	Robotics is the science that studies the technologies associated with the design and construction of robots. A robot is a device that, according to its programming, can perform certain tasks, operating in various ways either managed by humans or through programming	Increase productivity in various areas, from industry to domestic activities.	One way to use robots in the construction industry is during demolitions, a task that requires significant effort and energy from workers and poses a high risk of workplace accidents. Another application is the use of robots for masonry work; machines can be pre-programmed to place bricks in wall construction.
Blockchain	Gomes *et al.*, 2021. Arão; Yudi, 2023.	Blockchain is a tool designed for decentralizing processes, ensuring that information involved in a transaction becomes more secure and easier to manage within a system.	Blockchain is a unique, immutable, shareable, and distributed digital ledger that facilitates contractual relationships, transaction recording, and asset tracking within a business network.	The technology allows stakeholders of the same project to monitor in real time any changes or approvals made to a construction document. With blockchain, it is possible to track and verify the completion of the project and trigger clauses for payment automatically, in real time, and without human intervention.

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Continuation of Table 2: Main Digital Technologies in Construction 4.0

Artificial Intelligence (AI)	Damaceno; Vasconcelos, 2018. dos Santos Teixeira; dos Santos Teixeira; da Rocha, 2020	Artificial Intelligence (AI) refers to the ability of a machine to replicate human-like skills such as reasoning, learning, planning, and creativity. In software, AI is present in virtual assistants, image analysis software, search engines, and facial and voice recognition systems. In hardware, it is found in robots, autonomous vehicles, drones, and applications within the Internet of Things (IoT).	Processing large volumes of data, analyzing vast amounts of data, interpreting and categorizing data, and proposing mathematical models that assign meaning to the data.	In the construction industry, AI enables innovations such as intelligent software for automatically creating construction schedules or automating structural calculations. Another application is the use of AI in planning, development, and control of construction projects, where solutions with easily interpretable graphics contribute to the progress of the project with greater speed and predictability.
Aditive Manufacturing	Colpani, 2018.	Additive manufacturing, commonly known as 3D printing, involves creating products by layering material based on a three-dimensional (3D) digital model. This model is developed using software, and specialized machinery deposits the material as programmed.	Create three-dimensional (3D) digital models	For the construction sector, creating models through 3D printing helps in visualizing the project, aiding in planning and project presentation.
Drones	Decea, 2020. Gouveia *et al.*, 2021. Keyvanfa, Shafagha, Awanghamat, 2020.	Drones are unmanned aerial vehicles, also known as UAVs (Unmanned Aerial Vehicles), which are remotely controlled by a device called a remotely piloted aircraft (RPA). There are also more advanced drone models that can be controlled by a computer..	Capture aerial images	In the construction industry, drones provide various images from different angles for technical reports, assist in topographic surveys and area mapping, check for structural damage, inspect roofs, and can also support the marketing and sales team.

Source: Prepared by the authors (2024)

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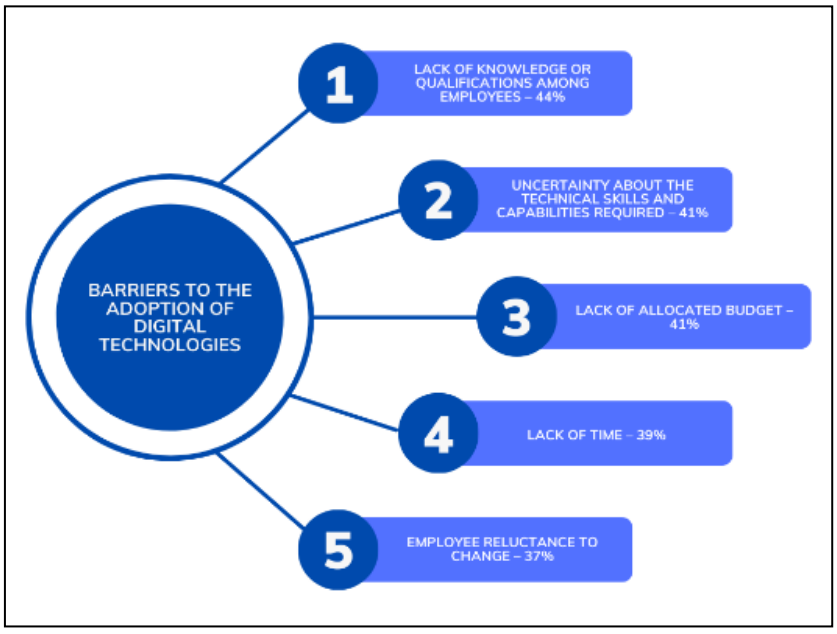
The digital technologies presented in Table 1 configure an interconnected environment, organizing processes and information to design, construct, and operate more effectively in the construction industry, particularly within construction companies (Sawhney *et al*., 2020).

The research report "The State of Digital Adoption in Construction 2023," developed for Deloitte and in collaboration with Autodesk, highlights significant differences following the adoption and use of digital technologies by construction companies. When asked about their current use of digital technologies related to construction, the most commonly used technology was Building Information Modeling (BIM), employed by 40% of the companies, followed by cloud computing (39%) and drones (37%). The study illustrates the current utilization of technologies in construction and engineering businesses, with notable mentions including Building Information Modeling (BIM), cloud computing, drones, Internet of Things (IoT), Artificial Intelligence (AI), blockchain, big data, and virtual and augmented reality (Deloitte, 2023). The report also identified the most common barriers to digital technology adoption in the construction industry, which are presented in Figure 2:

Figure 2: Common Barriers to the Adoption of Digital Technologies



Source: Prepared by the authors based on the "State of Digital Adoption in Construction 2023" report, Deloitte (2023).

The lack of technological innovation in the construction sector is a global reality and is particularly pronounced in Brazil. The absence of modernization and new technological solutions can lead to reduced productivity and, consequently, diminished competitiveness in the sector. Therefore, it is imperative for companies to identify barriers to modernization and develop innovation strategies (Linderoth; Jacobsson; Elbanna, 2018).

4. Metodology

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The field research was characterized by investigations that, in conjunction with bibliographic and/or documentary research, involved data collection from individuals or groups. Thus, the objective of the field research was to observe facts and phenomena exactly as they manifested in reality through data collection (Gil, 2022). The selection of the companies where the checklist was applied was carried out through a non-probabilistic purposive sampling process. According to Gil (2022), in this type of process, cases are chosen for the sample that are representative of the population/universe. For the development of this research, the selection criteria described in Figure 3 were used.

1. Companies certified at level A in the state of Pernambuco by the Conformity Assessment System for Civil Construction Services and Works Companies – SIAC PBQP-H/ISSO 9001.

2. The company belongs to a working group of a construction representative entity.

3. The company is engaged in a digital transformation program.

For the field research, the selection of construction companies located and operating in Recife-PE was conducted. Initially, ten companies were selected for contact and the application of the research checklist. However, only six responded to the survey: one large company, four medium-sized companies, and one small company. The classification of the companies was determined according to Sebrae guidelines (2020).

All companies that participated in the research are engaged in some form of digital transformation program, possess ISO 9001:2015 certification— the international standard for Quality Management Systems (QMS) published by the International Organization for Standardization (ISO)— and half of the companies hold Level A certification in the Brazilian Quality and Productivity Program for Habitat (PBQP-H).

Only two of the six companies participating in the research have a specific department dedicated to technological development or innovation, meaning they have strategic planning sectors for the adoption and implementation of digital technologies. This limitation affects the analysis of the dynamic process involved in creating and applying new technologies aimed at optimizing resources and boosting productivity, which constitutes the technological development of a company.

Data collection took place between August and November 2023, using a checklist developed based on the research models of Medeiros (2011), Huttl (2023), and studies on the following topics:

- Digital maturity of construction companies and real estate developers across Brazil (CBIC, 2023);
- Brazilian Construction Scenario Report 2023 (Cenário Construtivo Brasileiro, 2023);
- Digital 2023 Construction Report (RICS, 2023);
- Digitalization of Engineering in Brazil (BIM Fórum Brasil, 2022);
- The Future of Construction: Innovation in the Real Estate and Construction Sectors in Brazil (Deloitte, 2020);

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- Digital Transformation in the Construction Industry (CBIC, 2020);
- Digital Transformation: Building the Future, Today (BSI, 2020).

In the development of the checklist, the Likert scale was also adopted, which is a response format where respondents express their level of agreement with statements, ranging from strong disagreement to strong agreement. A Likert scale consists of questions where respondents not only agree or disagree but also indicate the intensity of their responses (Cunha, 2007; Alexandre *et al.*, 2003).

The checklist was divided into four parts:

1. General Information Registration for Company Characterization: This section includes the size of the construction company, whether the company has a specific department for technological development, and if it is engaged in any sector or training for digital transformation. It also identifies which work processes the construction companies most invest in financially.
2. Characterization of the Responsible Person: This section covers the academic background and position held by the interviewee within the company.
3. Digital Transformation: This section includes questions related to the level of digitization, motivations for adopting digital technologies, the focus areas of training and development, and the main barriers and benefits associated with the use of digital technologies in each studied construction company.
4. Digital Technologies: This section focuses on collecting information about which technologies are used in the construction companies, the impacts resulting from technological implementations, and the importance of implementing digital technologies to increase productivity.

The following presents the results of this research, which aimed to identify challenges, motivations, and actions taken by construction companies for the adoption and implementation of digital technologies across various company processes.

5. Presentation and Analysis of Results

5.1 Case Study

It was possible to identify the motivations that led the construction companies participating in the study to adopt digital technologies and the work processes where these technologies were implemented, as illustrated in Figure 3.

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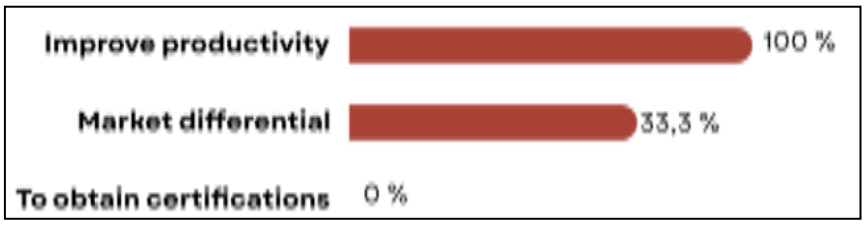
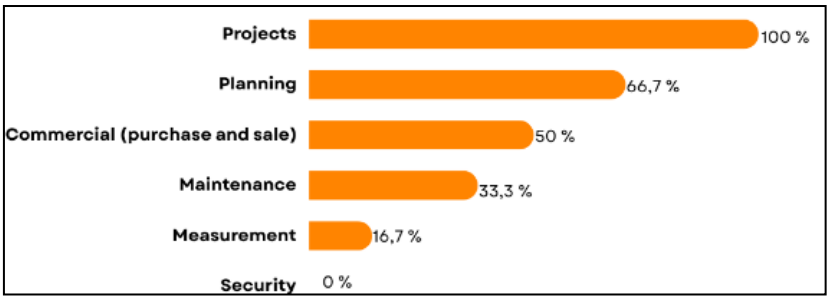
Figure 3: Motivation for the Adoption of New Digital Technologies



Source: Prepared by the authors (2024)

The present research mapped six processes where 100% of the companies reported that they started implementing digital technologies in the project sector, with the second sector being planning, as illustrated in Figure 2.

Figure 4: Processes for the Implementation of Digital Technologies



Source: Prepared by the authors (2024)

When construction companies start implementing digital technologies in their project sector, it ensures that designers work cohesively so that the executive projects are aligned. This improves planning by reducing errors and mistakes in budgeting and can also decrease delays in execution. However, the present research finds that the project sector is the most suitable for a construction company to begin a strategy for adopting and implementing digital technologies

To highlight the main benefits that the use of digital technologies brings to construction companies, the present research identified five potential benefits, with the following percentages as results:

- 83.3% of the companies highlighted process automation as the main benefit of using digital Technologies.
- 50% of the companies reported that cost reduction and improvement in the quality of projects are the second most significant benefits derived from using digital technologies.
- 33.3% agreed that the use of digital technologies led to increased productivity and improved managerial visibility.

For the present study, ten digital technologies were listed based on exploratory research, as shown in Figure 5, with the aim of mapping which of these technologies are most commonly used in construction companies. The results show that Building Information Modeling (BIM) is the most used technology, with 100% of the companies already employing BIM in their work processes.

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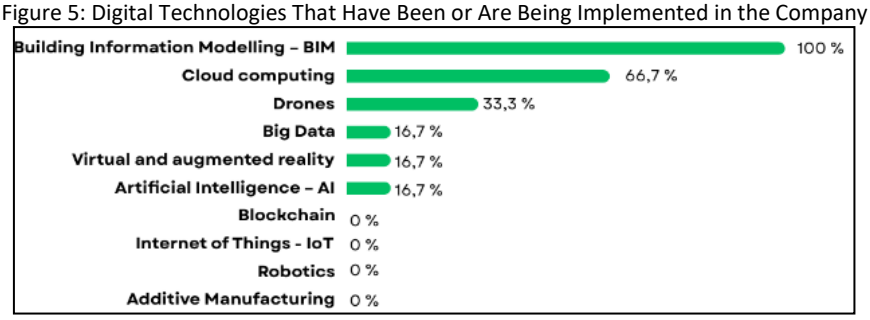
Figure 5: Digital Technologies That Have Been or Are Being Implemented in the Company



Source: Prepared by the authors (2024)

Given the results presented above and the motivations recorded in the research, it was found that the project processes in a construction company are the ideal place to start a strategy for implementing the use of digital technologies. It can be concluded that with the correct adoption of the technology to be used in accordance with the needs of the companies, the construction company presents greater benefits in automatic processes, that is, speeding up processes that would previously be carried out manually.

It is important that the process of implementing digital technologies in a construction company happens gradually, in a planned manner and in phases. Figure 6 shows that this research identified that the cost of adopting technological innovations is the main barrier to implementing digital technologies in its work processes.

Figure 6: Main Barriers Encountered by Construction Companies to Implement New Digital Technologies

Source: Prepared by the authors (2024)

The research confirmed that the cost of adopting and implementing digital technologies is one of the main barriers faced by companies. The study also aimed to identify which technologies incurred the highest costs for the companies, with the following results:

- Four companies (66.7%) agreed that BIM was the technology that incurred the highest costs for adoption and implementation.
- Cloud computing and Big Data were the technologies that incurred the highest costs for the companies (16.7%), after BIM.

To ensure that a digital technology is implemented correctly and brings benefits to the construction company, it is recommended that the company seek specialized consulting and training to understand how the technology works and how to use it according to its needs. Figure 7 shows satisfactory results regarding the training and/or capacitations carried out by

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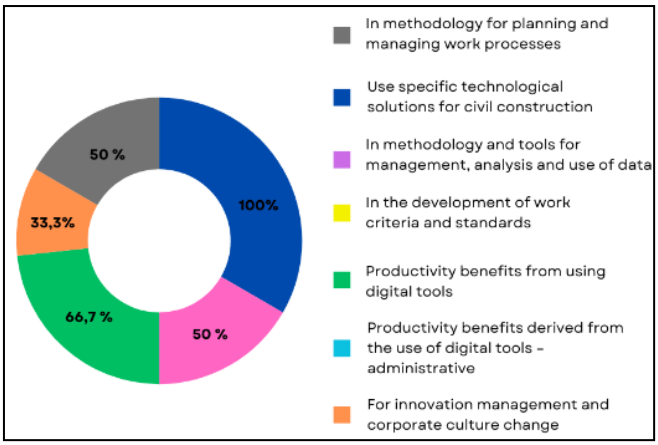
construction companies, where 100% of the companies prioritize training focused on the use of technology solutions specific to construction.

Figure 7: Training and/or Capacitations Conducted by Construction Companies



Source: Prepared by the authors (2024)

Analyzing the results presented earlier and considering that the construction sector is one of the least digitized industries worldwide, as discussed in the theoretical framework, it is possible to conclude that the lack of organizational culture oriented towards digital transformation and the cost of adopting technologies are the most significant factors causing construction companies to resist the adoption and use of digital technologies.

5.2 Guidelines for implementing digital technologies in construction companies

Based on the information collected and experiences gained through the review of the state of the art and field research that make up this work, steps are established for the implementation of digital technologies in construction companies. Table 3 below suggests guidelines for each stage of implementing digital technologies in construction companies.

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Table 3: Guidelines for Each Stage of Implementing Digital Technologies in Construction Companies

Stage	Guideline 1	Guideline 2	Guideline 3
Diagnosis: Identification of the company's needs	Identify the strengths and weaknesses of the construction company to then define the objectives and goals, ensuring that digital technology will be applied effectively.	Evaluate the maturity level by applying the digital transformation maturity models presented and described earlier in Chart 2 - Main Digital Transformation Maturity Models	Investigate the challenges faced by your employees. This can be done through interviews with staff, analysis of existing processes, and customer feedback.
Methodology: Implementation Outline	Determine which technologies are most suitable for the processes or work areas selected for adoption and use, considering factors such as the type of projects undertaken and the available budget.	Also define a team of employees who will be responsible for carrying out the activities related to this process, including identifying which professionals will undergo training and test the digital technologies adopted in the company's processes.	Conduct research on available digital technology options in the market and identify those that best meet the company's needs, through consulting with specialized technology and innovation companies or through partnerships with educational institutions.
Action Plan: Determining Activities for Implementation	Clearly outline the activities that need to be developed, for example, by using action plans, including timelines, resource allocation, team training, and success metrics.	Train employees to use the new digital technologies, which involves providing appropriate training and development on how to use the new technologies effectively and productively, through companies or professionals specializing in the digital technologies chosen by the company.	List the expected benefits so they can be evaluated at the end of the implementation process.
Implementation: Pilot and Testing	Evaluate the selected digital technologies in small-scale projects within the company to analyze their feasibility and effectiveness under real working conditions.	Evaluate the test results to determine which obstacles were encountered and what improvements will be necessary.	If, after testing, the digital technology is indeed selected, the company should determine the next projects for implementation and integration processes.
Integration of Digital Technologies	Begin implementation gradually throughout the construction company, starting with processes where the technologies can provide the most significant positive impact.	Continuous monitoring of performance and adjustments as needed for one or more implemented digital technologies.	Perform a comparative study with the expected benefits, such as increased productivity, reduced errors, improved quality of work, and higher customer satisfaction.

Source: Prepared by the authors (2024)

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It is recommended that construction companies operating in the real estate sector, who wish to implement digital technologies, engage in programs, journeys, and events focused on digital transformation and technological innovations in the construction sector. Examples include:

- Projects from the Brazilian Chamber of the Construction Industry (CBIC)
- Brazilian Strategy for Digital Transformation (E-Digital)
- Digital Transformation Journey – SENAI
- Center for Advanced Studies and Systems - CESAR in Recife, located in Porto Digital.

Knowledge and updates on technologies and innovations available in the market are essential for defining the company's approach to innovation and digitalization, aligned with the business strategy, always focusing on generating results. However, for a construction company to achieve satisfactory results in the implementation of digital technologies, it is crucial to follow the guidelines presented in Table 3.

5. CONCLUSIONS

The construction industry faces significant challenges but also has the potential to reinvent itself and adapt to the new demands of an ever-evolving world, undergoing a significant transformation driven by Industry 4.0. Innovations are being applied on-site and in project management with the aim of improving quality, reducing costs, and mitigating risks.

The exploratory research identified that technological advancements in the construction industry, which enhance efficiency and productivity, contribute to increased efficiency and productivity in this sector. The research also identified a variety of technologies that are useful in the construction industry, including: Building Information Modeling (BIM), Internet of Things (IoT), Augmented and Virtual Reality, Digital Twins, Big Data, 3D Printing, Cloud Computing, and Blockchain.

In the case study, despite the limited number of responses to the research checklist, it was possible to observe that digital transformation in the construction industry is essential for the sector’s economy and that, in a construction company, this transformation should begin with the project sector. Building Information Modeling (BIM) stands out as the predominant technology among construction companies, and the reduction of costs and consolidation of the company in the market are direct results of adopting new technologies. Finally, the cost of developing/adopting technological innovations and clients' conservatism are the main barriers to digital transformation.

Given the above, the work has achieved the purposes established by the objectives, which were to identify, systematize, and record knowledge about digital technologies with the aim of structuring better practices applied to construction companies.

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