DIGITAL TRANSFORMATION IN CIVIL CONSTRUCTION: A PROPOSAL FOR THE IMPLEMENTATION OF CONSTRUCTION 4.0 IN SMALL COMPANIES

TRANSFORMAÇÃO DIGITAL NA CONSTRUÇÃO CIVIL: UMA PROPOSTA DE IMPLEMENTAÇÃO DA CONSTRUÇÃO 4.0 EM PEQUENAS EMPRESAS

TRANSFORMACIÓN DIGITAL EN LA CONSTRUCCIÓN CIVIL: UNA PROPUESTA DE IMPLEMENTACIÓN DE LA CONSTRUCCIÓN 4.0 EN PEQUEÑAS EMPRESAS

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ABSTRACT

This study investigates the transition of the construction industry to the Construction 4.0 paradigm, focusing on overcoming productivity stagnation and the sector's technological slowdown. The global scenario, driven by the Fourth Industrial Revolution, requires the integration of technologies such as BIM, drones, the Internet of Things, and cloud computing. However, the literature indicates that implementation is challenging, especially for small companies in developing countries, due to high costs, cultural resistance, and the lack of clear roadmaps. The case study conducted in a small construction company in Pernambuco highlights real issues, such as failures in façade inspection and critical incompatibilities between decentralized projects. To address these bottlenecks, an eleven-step methodology is proposed, using Revit software for BIM coordination, the OnSafety platform for digital occupational safety management, and the strategic use of drones for technical monitoring. The results demonstrate that digitalization is feasible and essential for small organizations, leading to greater operational efficiency, error reduction, and increased competitiveness in the regional market.

Keywords: IR4.0. Construction 4.0. Digital Solutions. Drones. Mobile Computing. BIM.

RESUMO

Este trabalho investiga a transição da indústria da construção para o paradigma da Construção 4.0, com foco em superar a estagnação da produtividade e a lentidão tecnológica do setor. O cenário global, impulsionado pela quarta revolução industrial, exige a integração de tecnologias como BIM, Drones, Internet das Coisas e Computação em Nuvem. Contudo, a literatura aponta que a implementação é desafiadora, especialmente em pequenas empresas de países em desenvolvimento, devido a custos elevados, resistência cultural e falta de roteiros claros. O estudo de caso realizado em uma construtora de pequeno porte em Pernambuco evidencia problemas reais, como falhas na inspeção de fachadas e incompatibilidades críticas entre projetos descentralizados. Para solucionar esses gargalos, propõe-se uma metodologia em onze etapas que utiliza o software Revit para

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compatibilização BIM, a plataforma OnSafety para gestão digital de segurança do trabalho e o uso estratégico de drones para monitoramento técnico. Os resultados demonstram que a digitalização é factível e essencial para pequenas organizações, resultando em maior eficiência operacional, redução de erros e aumento da competitividade no mercado regional.

Palavras-chave: IR4.0. Construção 4.0. Soluções Digitais. Drones. Computação Móvel. BIM.

RESUMEN

Este trabajo investiga la transición de la industria de la construcción hacia el paradigma de la Construcción 4.0, con foco en superar el estancamiento de la productividad y la lentitud tecnológica del sector. El escenario global, impulsado por la Cuarta Revolución Industrial, exige la integración de tecnologías como BIM, drones, Internet de las Cosas y computación en la nube. Sin embargo, la literatura señala que la implementación es desafiante, especialmente en pequeñas empresas de países en desarrollo, debido a los altos costos, la resistencia cultural y la falta de rutas claras. El estudio de caso realizado en una constructora de pequeño porte en Pernambuco evidencia problemas reales, como fallas en la inspección de fachadas e incompatibilidades críticas entre proyectos descentralizados. Para solucionar estos cuellos de botella, se propone una metodología en once etapas que utiliza el software Revit para la coordinación BIM, la plataforma OnSafety para la gestión digital de la seguridad laboral y el uso estratégico de drones para el monitoreo técnico. Los resultados demuestran que la digitalización es factible y esencial para pequeñas organizaciones, resultando en mayor eficiencia operativa, reducción de errores y aumento de la competitividad en el mercado regional.

Palabras clave: IR4.0. Construcción 4.0. Soluciones Digitales. Drones. Computación Móvil. BIM.

1 INTRODUCTION

The global industrial scenario has changed radically in recent years, as a result of continuous technological innovations (SCHMIDT *et al.* 2015). While the first three industrial revolutions leveraged productivity through disruptive technologies (SCHUH *et al.* (2013), Industry 4.0 (I4.0) introduced the concept of smart factories. This new paradigm encompasses advances such as Cyber-Physical Systems, Internet of Things (IoT), Robotics, Big Data, Cloud and Augmented Reality (WEYER *et al.* 2015), driven by the intense convergence between the digital, physical and biological worlds (LI *et al.* 2017).

In the field of civil construction, this concept gave rise to Construction 4.0. The literature extensively maps its applications: Oesterreich and Teuteberg (2016) point out 16 areas integrated into the sector, while Balasubramanian *et al.* (2021) reference at least 23. In a convergent way, Silva, Simão and Menezes (2018) summarize that the insertion of tools such as drones, cloud, augmented reality, 3D printing and BIM are promoting profound transformations in the work dynamics in civil construction (CC).

Although digitalization facilitates the construction and maintenance processes (MUSARAT *et al.* 2022), the sector has traditionally been slow to assimilate innovations (CAO; LI; WANG, 2014), failing to take advantage of technological opportunities capable of combating the productive stagnation of the workforce (MASKURIY *et al.* 2019). Aggravating this scenario, Menegon and Da Silva (2023) point out the difficulty of implementing Construction 4.0 in small companies in developing countries. The authors warn of a scientific gap, highlighting the urgency of adapting research to the local reality of emerging markets and their specific barriers.

The construction industry is highly fragmented, dominated by small and medium-sized companies with restricted budgets to invest in innovation, has obstacles such as high startup costs, training expenses, resistance to change, and technological immaturity often restrict I4.0 to purely experimental stages.

Similar to the panorama of general stagnation of the sector (MASKURIY *et al.* 2019), the construction company object of this study has a cultural aversion to change. The non-adoption of digital advances has generated severe bottlenecks, such as operational inefficiency, slow decisions, failures in project management, and consequent loss of competitiveness in the market.

However, the literature proves that these barriers can be mitigated. The application of I4.0 ensures greater efficiency on construction sites (MUSARAT *et al.* 2022), and the use of intelligent tools in supply management generates time savings and cost reduction (DARDOURI, 2022). Therefore, the adoption of these technologies presents itself as a viable and promising way to solve the problems of the company in focus.

The article presents a structure organized as follows: section 2 presents the theoretical framework with concepts and elements of IR4.0 and digital transformation in CC; Section 3 consists of a case study, with a proposal for the company studied; Section 4, finally, contemplates the conclusions of the study and final considerations of the work.

2 THEORETICAL FRAMEWORK

2.1 INDUSTRY 4.0 IN CIVIL CONSTRUCTION

IR4.0 created a paradigm shift in the construction industry towards digital transformation, this transition of the sector to a more advanced digitalization resulted in an innovative concept called Construction 4.0. The term Construction 4.0 was derived from the concept of Industry 4.0, which has its roots in the German manufacturing sector (OSUNSANMI; AIGBAVBOA; OKE, 2018). According to Musarat *et al.* (2022), digitalisation in the construction sector, has facilitated construction and maintenance processes. Not only in the execution phase, but digitalization is also in all other phases of construction projects, providing greater ease to builders. Musarat *et al.* (2022) also bring in their studies that the advent of IR 4.0 is essential for the smooth transformation of the construction industry towards digitalization.

Construction 4.0 adapts to the Industry 4.0 framework by incorporating cyber-physical systems and advanced digital technologies into its practice according to Sawhney *et al.* (2020). To align with Industry 4.0, CC needs to transform significantly, deploying technologies (SHAFEI *et al.*, 2022).

Information from the World Economic Forum (WEF, 2016) points out that the adoption of digital technology increases productivity, streamlines project management and procedures, and increases quality and safety; also in this line and as highlighted by CBIC (2016), the adoption of innovations is a viable option to better meet the demands of the civil construction sector. The use of innovations has several advantages, such as reducing labor costs, increasing productivity, and decreasing production costs.

According to Simão *et al.* (2019), to make this smart industry model viable, some crucial aspects are necessary, such as adaptability, optimization of the use of resources, and connection between all participants, from value generation to strategic implementation.

2.2 DIGITAL TRANSFORMATION IN THE CONSTRUCTION INDUSTRY

Digital transformation aims to improve an entity, generating significant changes in its characteristics through the use of information technology, computing, communication, and connectivity (VIAL, 2019). Digital transformation is unavoidable in the era of Industry 4.0. According to Brynjolfsson and Hitt (2000), digital transformation can improve organizational performance by providing products or services that adapt to customer preferences, increasing customer satisfaction and reducing costs. Change and transformation are driven by and built on digital technology.

According to Morakanyane *et al.* (2017), one of the effects of digital transformation on an organization is the development of competitive advantage. They also say that digital transformation should be viewed as a comprehensive organizational approach, rather than simply changing the way of operating from online to analog or from analog to digital. Digital transformation is seen as a continuous and never-ending process.

Verhoef *et al.* (2021) identify three main reasons why companies should digitally transform: evolution in digital technology, increased digital competition, and changes in consumer behavior in response to the digital revolution.

2.3 CONSTRUCTION 4.0

According to Musarat *et al.* (2022), digitalization is the new norm in the construction industry, following the adaptability of the fourth Industrial revolution. In the construction industry, digital transformation requires a variety of technologies, newly proposed methods utilizing digital technology for the development of the construction sector, energy optimization, sustainable environment, smart construction to deliver a better quality of life, economic and architectural growth, wireless technology for effective communication, and building maintenance (MUSARAT *et al.*, 2021).

Similar to the manufacturing sector, the construction sector can also be a major beneficiary of I4.0. The implementation of I4.0 will ensure that production efficiency is achieved through the utilization of advanced technologies, such as mechanized automation, to operate without human intervention. The benefits are quite obvious, as this implementation not only improves product quality, but also reduces distribution time, which will further increase the performance of the operation (NAWI *et al.*, 2021).

The transition to more advanced digitalization has resulted in an innovative concept called Construction 4.0. The term Construction 4.0 was derived from the concept of Industry 4.0, which has its roots in the German manufacturing sector (OSUNSANMI; AIGBAVBOA; OKE, 2018). Construction 4.0 adapts to the Industry 4.0 framework by incorporating cyber-physical systems and advanced digital technologies into its practice, according to Sawhney *et al.* (2020).

According to the World Economic Forum (WEF, 2016), the adoption of digital technology increases productivity, streamlines project management and procedures, and increases quality and safety. To align with Industrial 4.0, the CC industry needs to transform significantly, deploying technologies (SHAFEI et al., 2022). The advent of I4.0 is essential for the smooth transformation of the construction industry towards digitalization (SUBRAMANIAN, 2022).

Digitalization in construction has transformed construction projects from planning to closure (WIJAYASEKERA, 2022) due to the involvement of various technologies such as automation, cybersecurity, Internet of Things, drones, Building Information Modeling (BIM), 3D printing, Augmented Reality, etc (MUSARAT et al., 2022). Silva, Simão and Menezes (2018) summarize that the insertion of several technologies that are bringing significant changes in the way CC works are drones, cloud computing, augmented and virtual reality, additive manufacturing, BIM and automatic tracking.

While the construction industry has immense potential, the only way forward to achieve maximum efficiency and production is through the incorporation of new technologies, digitalization, and innovation for the construction industry. The incorporation of newly evolved industry tools that have already established themselves as successful aids to the construction industry, such as three-dimensional digitalization, the use of drones, and information modeling, should be incorporated into current practices and perceptions of the construction business, the path chosen to address these difficulties will be significantly improved (NAWI *et al*., 2021).

The literature is broad regarding the concepts and applications of the various areas of IR4.0, such as the approach of the authors Tondelo and Barth (2019), Dos Santos, Mota and Zanlucas (2021) and Zhang *et al.* (2016), which in general address the areas of IR4.0 applied in CC with the themes: use of drones, BIM and mobile computing, respectively, whose areas were worked on in the case study below. Some authors and researchers bring important concepts and explain in the literature the various areas of construction 4.0, some relevant are:

Drones , which are aircraft capable of flying without a human operator on board (FALORCA; LANZINHA, 2018) and that according to Mosly (2017), the use of this equipment can help reduce the time of activities, increase the quality of work, improve safety standards and reduce costs. Studies developed in the area by Nwaogu *et al.* (2023) bring a review of the literature corroborating and expanding these concepts.

The Internet of Things (IoT) which, according to Pataca (2021), is related to the ability of objects to communicate and transmit information about their state and operation. Filho (2016) says that IoT technology consists of connecting objects of daily use in the real world with the Internet, transforming them into smart objects. Mishra, Lourenço and Ramana (2022) and Elghaish *et al.* (2021) review the literature delving into the topic.

According to Paz and Loos (2020), cloud computing allows the creation of new business models based on the data available in the cloud. This information allows users to predict the closure of production lines, schedule add-on lines remotely, and make adjustments in real time. Bello *et al.* (2021) and Ali *et al.* (2020) through their literature reviews bring other contributions to their studies in the area.

Building Information Modeling (BIM) offers tools to transform and improve project performance and productivity, decreasing inefficiencies and decreasing unproductivity, as well as increasing collaboration between different groups of project stakeholders (BURGESS; JONES; MUIR, 2018). Through a digital platform, BIM enables the teams involved in the project to share information, visualize the interactions between the project disciplines in an integrated way, and make decisions that improve project performance (MAHALINGAM; YADAV; VARAPRASAD, 2015). Recent research by Ramly, Mohamad and Noor (2023), Wang and Chen (2023), Caldart and Scheer (2022) and Avendaño *et al.* (2022) bring a relevant literature review on the tool.

Mobile computing is a computing paradigm that allows users to access and interact with data, applications, and services through handheld devices without the need for a physical connection to a fixed network or infrastructure. Andrade, Assis and Brochardt (2015) highlight the importance of using mobile devices, such as smartphones and tablets, to improve the flow of information on the construction site. Marques *et al.* (2020) and Nazir *et al.* (2019) also present research in the area.

According to Kirner and Kirner, (2011), computer interface techniques that incorporate three-dimensional space, such as virtual reality, augmented reality and their variations, allow the user a multisensory experience. Li *et al.* (2023), Muthalif, Shojaei, and Khoshelham (2022), and Cárdenas-Robledo *et al.* (2022) bring important research today in their literature reviews.

Finally, Additive manufacturing, which, according to Ngo *et al.* (2018), 3D printing consists of an additive manufacturing method used in the production of a wide range of complex structures and shapes, originating from information from three-dimensional models. This technique involves printing consecutive layers of materials to create the desired object. Other definitions and studies are characterized in the research of Gardner (2023), Pajonk *et al.* (2022), Raza and Zhong (2022) and Coelho *et al.* (2021), through their literature reviews.

3 CASE STUDY

3.1 PRESENTATION OF THE COMPANY

Despite a slow implementation, the construction industry has sought more support from technological innovations, recognizing the value of technology as a competitive differentiator. However, the fragmentation of the sector, with many small and medium-sized companies, as well as the challenges of implementing Industry 4.0, currently limit the application of technologies and keep the sector at an experimental stage. Digitalization of the construction industry, coordinated with high-level strategies and initiatives, can increase the competitiveness of the sector, improve operational efficiency, and generate significant benefits.

In this context, the company studied, in view of its problems and limitations, seeks greater competitiveness in the market, adopting technological solutions of construction 4.0. The company in focus is a small company, operating in the interior of the State of Pernambuco in the field of civil construction, has approximately 100 employees, routinely works with subcontractors, having its activity in the market since 2013. The company has 6 works in progress, in the cities of Paudalho, Buenos Aires and São Vicente Férrer, from the construction of multi-storey buildings, renovations of public buildings, paving in cobblestone and interlocked, basic sanitation, among other services.

It is a family business, culturally averse to change and that has not kept up with digital advances or adopted solutions that improve its construction, management or planning processes, as the scenario of recent years has required it to do, remaining stagnant in this sense. The situation of non-implementation of digital advances in the sector generates problems in the company such as: low operational efficiency, delays in decision-making, difficulties in project management and reduced competitiveness in the market due to lack of investment in digital solutions.

3.2 PROBLEMS FACED IN THE COMPANY

- Services with difficult access and inspection on facades

Image 01 shows past situations in which there was difficulty in relation to the inspection of various services. Image 01 shows the execution of a roof in a construction site in São Vicente Férrer-PE, whose access to the service is difficult and the engineer responsible for the visual inspection was unable to perform a satisfactory analysis of the services.

Figure 1

Installation of purlins in a roof

Source: Author, 2023

As the company studied, it does not have the use of drones for inspection and inspection of these services. The use of drones would facilitate real-time monitoring of the execution of covering services and the inspection of employees in compliance with regulatory standards for work safety. It would also be possible to carry out visual inspection on building facades in order to identify possible pathological manifestations or construction defects.

- Incompatibility between projects

In 2020, the company in this study started the construction of a 3-story mixed building with a built area of 1115.00 m² in the city of Paudalho-PE, according to plans (Figures 02 and 03), the elaboration of the projects took place in a decentralized way, with different authors from the areas of architecture, structural calculation, electrical installations and hydrosanitary installations. Even after the critical analysis of the respective projects by the company's technical staff, during the execution of the work some incompatibilities between projects emerged, such as:

I. Compatibility between architectural and structural design

Conflict: BWC Soc. window positioned entering Pillar P07.

Location: apartments 01, 03 and 05.

Procedure performed: Move the window back facing the pillar.

II. Compatibility between the design of electrical installations and hydrosanitary installations

Conflict: Intersection between conduit and air conditioning drain pipe in the wall

Location: apartments 01 to 06.

Procedure performed: Conduit repositioning.

III. Compatibility between structural and plumbing installations

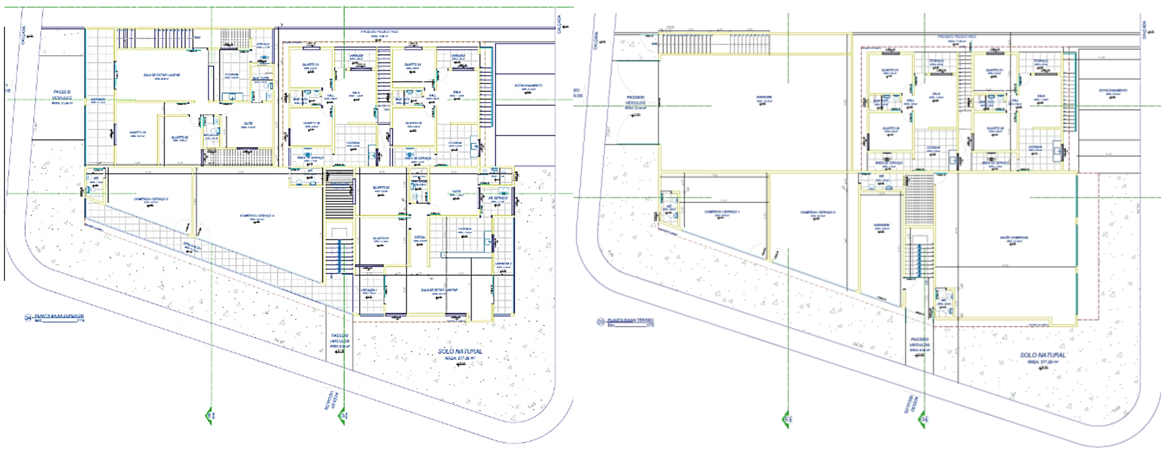
Conflict: Crossing between sewer pipe and V50 beam, in which its section height did not allow the passage of the DN100 sewer pipe.

Location: ground floor.

Procedure performed: Change in the structural design with adjustment in the height of the beam.

Figure 2

Ground floor plan Figure 03 – Upper floor plan



Source: Author, 2023.

This situation confirms the studies by Dos Santos, Mota, and Zanlucas (2021) that during the execution of projects (hydraulic, structural, and electrical), many elements end up generating physical and functional conflicts, due to the constraints of each system. These unresolved interferences in the design phase caused interruptions in construction for project review, or the need for sudden decision-making on site, disfavoring work and the optimization of time and resources.

- Mechanical processes in the management of workers' safety and health

The company studied uses mechanical processes on paper for all its management of workers' safety and health (OSH), such as: control and delivery of personal protective equipment (PPE), employee training, reports and records of evidence and non-conformities and the safety inspection checklist.

This methodology, already outdated, generates delays, does not bring effectiveness in the decision-making process, as well as limits and delays access to information.

3.3 PROPOSAL FOR SOLVING THE PROBLEM IN THE COMPANY

Considering the size of the company under study and the problems it faces in its projects, a proposal was prepared for the adoption of digital tools and solutions for the company, such as: use of drones, implementation of BIM and use of mobile computing.

The use of BIM technology will take place with the use of Autodesk's Revit software (2023), to make projects compatible, on a multidimensional platform, also adding to the *software* the OrçaBIM plugin from the company 3F Ltda – OrçaFascio, obtaining more expressive results in combination with the budget of works.

The company will be offered drone equipment for monitoring the works, services where there is difficult access and inspection of facades, the company will be proposed the acquisition of an intermediate-sized, long-range model, flight time duration over 30 minutes and a high-definition camera.

The use of mobile computing for the OSH management area will be carried out by a mobile solution tool that facilitates integration, collection and communication in the area of Occupational Safety. The company's engineering, occupational safety and management team opted for the adoption of the *OnSafety* platform from Lean Tecnologia e Engenharia LTDA. With the implementation of this tool, it will be possible to digitize the area of worker safety and health management in the company. Obsolete mechanical processes will be replaced by a set of digital solutions, such as: digital PPE sheet, issuance of inspection reports, CIPA documentation, Registration Control for Employees, among others. The software allows everyone involved to use the same *workflows* to monitor the workplace, required training, the control and delivery of PPE, health monitoring, among other documents and requirements. It also allows the management of OSH audits carried out in the work environment, ensuring more effectiveness in the decision-making process and access to information and reports on different devices.

With the adoption of established digital tools and solutions and the objectives of implementing these solutions in the company defined in: Increased operational efficiency; Improved decision-making; Improvement of project management; Innovation and competitiveness and Training and professional development, it is possible to propose a sequencing of steps for the implementation of these solutions in the company studied with the proposals:

1) Acquisition of equipment and software;
2) Internal and external training and training in the areas addressed;
3) Implementation and use of technology;
4) Communication and engagement: Monthly meetings with teams to discuss advances, challenges, and results. Internal newsletters highlighting the benefits and improvements achieved with digital solutions and dissemination of innovations and results on the company's social networks and communication channels.
5) Evaluation and continuous improvement**:** Conduct quarterly evaluations of the results obtained with digital solutions. Identify areas for improvement and promote adjustments and optimizations in the processes and solutions implemented. Establish partnerships with specialized companies and institutions to stay up-to-date on new technologies and trends

4 CONCLUSIONS

As shown in the literature explained, IR4.0 brings several aspects, concepts and new technologies to the construction industry. Digital transformation in civil construction is inevitable.

The case study addressed here shows that it is feasible to implement digital solutions in the company through the problem solving proposals presented here. The adoption of drones for façade inspection can be an efficient and economical tool for the early detection of problems in buildings, as well as their use in services where there is difficult access, being possible and beneficial their implementation in the company.

It is also feasible to implement the BIM tool in the company, given that as Dos Santos, Mota and Zanlucas (2021) show, there are several advantages that the use of this technology includes, such as agility in compatibility, automatic analysis of problems between elements, effective communication between processes and the significant reduction of errors in the project. Matching helps prevent problems from being discovered during construction, which can result in unplanned costs and delays in correcting these flaws.

On another point, similarly to Zhang *et al.* (2016), addressed in their research that an innovative IT-based solution for site safety inspection approach not only eliminates redundant paper-based systems, but also improves the coordination and integration of information between safety inspection procedures and other safety management strategies, today intelligent mobile computing software and tools are possible to implement in construction companies, such as the *OnSafety* platform, presented.

The effective adoption of these digital solutions proposed for the construction company under study will put into practice the company's quest to incorporate areas of construction 4.0, reaping benefits that can be raised in future studies.

During the process of preparing this article, some limitations were identified, such as the lack of similar case studies in the researched literature and the scarce application of the IR4.0 areas addressed here in small construction companies. As a limitation of the study, the analysis of this study is valid only for the case that was investigated, and cannot be generalized to other situations.

The development of this article encourages the exploration of other areas of IR4.0 that could not be implemented or proposed in the company studied. It is therefore suggested that future studies develop similar studies in small companies in the CC sector with other adoptions of digital solutions.

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