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Industry 4.0 Innovations in Construction: Proposal of a Maturity Model

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Abstract

The dawn of the Fourth Industrial Revolution, better known as Industry 4.0, is set to enable global networks of machines and equipment in an environment of smart factories, capable of instantly exchanging information in an independent manner and having the Internet of Things and Cyber-Physical Systems as backbone for an autonomous operation. Great gains in productivity and flexibility are expected, which tend to intensify global competitiveness, promote social changes and economic development, besides stimulating new academic works, such as the proposal of models capable of identifying the maturity level of an organization in this context. Therefore, the present work proposes a maturity model to measure the maturity level of civil construction companies regarding the adoption of technologies and practices of Industry 4.0. Based on a systematic literature review, the proposed model was built from existing maturity models and their characteristics and relevant components. The model is supported by a elaborated questionnaire of twenty-three questions considering four dimensions (Technology, Organization, People and Sustainability) which was submitted to seven different companies in the city of Manaus/Brazil. The results after the practical application of the model showed that most companies had a low level of adoption of Industry 4.0 principles and there is plenty of room for improvement.

Keywords: Innovation; Industry 4.0; Construction; Engineering; Maturity Model;

1. Introduction

Civil construction is one of the most relevant sectors responsible for the development of any national economy since it is capable of generating thousands of direct jobs (core activities) and many more indirect jobs (other sectors such as IT), besides operating high amounts of capital. Many studies, including the World Bank (1984), confirm that there is a strong connection between civil construction and the rest of economy where any variation of demand eventually reflects on other sectors, from the supply of raw material to national employment rates.

Considering the Brazilian scenery and comparing to other sectors, construction is the one industry with the most capability of reducing poverty because of the great size of workforce, large amount of revenues due to government taxes and variety of companies involved. According to the latest report by the Brazilian Construction Chamber in 2020 the industry accounted for 3,3% of the national gross national product (GDP), although it represents a decline compared to recent times (2012-2013) when it added up to 6,5% of the GDP.

Frigieri & Zilbovicius (2002) mention that due to the particularities of the productive processes, the classic management tools usually employed in other industries face barriers to be used in constructions.

In general, Brazilian constructions are characterized by the lack of quality, delays and waste. The low efficiency and production quality, combined with low professional qualification and high turnover of labor can be pointed out as some of the factors that hinder the evolution of the sector.

Technological innovations are not so easily adopted in the production processes of construction companies. The investment in training the workforce so that new management technologies can be used and for carrying out R&D within companies are some of the challenges to be overcome in this decade so that there is a technological evolution (FIRJAN, 2014).

According to the OECD Oslo Manual (2005), innovation is "the implementation of a new or significantly improved product (good or service), or a process, or a new marketing method, or a new organizational method in business practices, in the workplace organization or external relations". For Loosemore (2014), innovation ends up being a factor of competitive advantage, where old ideas are replaced by new ideas, from an invention or an existing technology.

Despite being behind the rest of the world, the Brazilian civil construction sector is adopting technological innovations that have become standard practice in other areas, such as projects carried out entirely in virtual environments which leads to greater control of construction and labor. The market is moving from CAD (Computer Aided Design) tools to BIM (Building Information Modelin), which represents a major change in practice and innovation in civil construction (LEUSIN, 2018).

The term Construction 4.0 was coined to be the correspondence of Industry 4.0 in the construction industry and it refers to its automation and digitalization. Consequently, it aims at the development of a virtual building environment throughout a project lifecycle and assisted by technology.

From the aforementioned aspects, the present work aims to identify which technologies and practices from Industry 4.0 are being used in the construction area, in addition to develop a method of measuring the level of adoption of such technologies and practices. The proposed maturity model was applied to construction companies based in the city of Manaus (Brazil) and the results indicated their level of adherence to Construction 4.0.

Thus, in the theoretical scope, this study is relevant when approaching concepts of Industry 4.0 and its pillars, in addition to associating them with the field of engineering by identifying the most relevant technologies applied to civil construction, and assisting future research related to the area. Also noteworthy is the contribution to the proposed theme from the practical application of measuring the adoption of new technologies in construction companies.

This paper is divided into 4 sections as described below:

Introduction – Contextualization of the theme, desired objectives and justification and relevance of work.

Theoretical Reference – Literature review of the main concepts of Industry 4.0 and its relation to civil construction.

Methodology – Methodological procedures and tools chosen to carry out the research.

Results – Presentation of the proposed Maturity Model and its results.

2. Theoretical Reference

2.1 Industry 4.0

The first use of the term Industry 4.0 dates back to 2011, during the Hannover Fair, which is a traditional global meeting point for various industrial segments. In 2013, the term was officially adopted to designate the German initiative to remain a world pioneer in the innovations that are currently transforming the manufacturing sector. Industry 4.0 symbolizes the beginning of the Fourth Industrial Revolution.

Since its conception in 2011, many authors have tried to define the term Industry 4.0, and although there is no exact definition of the concept, there is clearly an understanding of its importance not only for the industrial sector, but for society as a whole (HERMANN et al., 2016). There are more than one hundred definitions for Industry 4.0, always involving the concept of networks of manufacturing resources (machines, robots, storage systems and facilities) that are autonomous and capable of controlling themselves according to different situations.

According to Hermann et al. (2016), Industry 4.0 embodies the current trend of automation technologies in the manufacturing sector, and it is mainly based on enabling technologies such as cyber-physical systems (CPS), cloud computing and the Internet of Things (IoT). There is a strong integration between the virtual and physical environment, in addition to new production systems to enable these transformations.

Industry 4.0 is synonymous with "Fourth Industrial Revolution", "advanced manufacturing", "smart factory" and "intelligent factory" as stated by Coelho (2016). The author also affirms that all these terms adequately portray the concept of what manufacturing plants will look like in the future. Based on this vision, factories will be equipped with much more intelligence, flexibility and dynamism, integrating into all stages of the value chain (product development, production, sales, marketing, distribution, etc.)

Bringing it to the Brazilian perspective, Industry 4.0 is characterized by digital information according to a report by the Federation of Industries of the State of Rio de Janeiro – FIRJAN (2016). The entity has the vision that information technology becomes an essential part of industrial processes, and decisions are automatically made through the use of an enormous set of data (Big Data). The technologies that need to be adopted to make Industry 4.0 feasible are also listed: Internet of Things, Big Data, advanced manufacturing, analytics, simulations, automated robots and augmented reality.

However, this term is still not widely used in Brazil, and according to the National Confederation of Industry - CNI (2016) this fact is an obstacle to the adoption of technologies in the country. In a survey carried out among several companies, it was found that only 48% of them use at least one of the technologies of the Fourth Industrial Revolution. Among large companies this number rises to 63% and reduces to 25% in small companies.

The technologies that are currently associated with the concept of Industry 4.0 can be classified as physical (3D printing, advanced robotics, autonomous vehicles, among others), digital (Internet of Things) and biological (biotechnology and genetics) are interconnected due to digital technologies (SCHWAB, 2016).

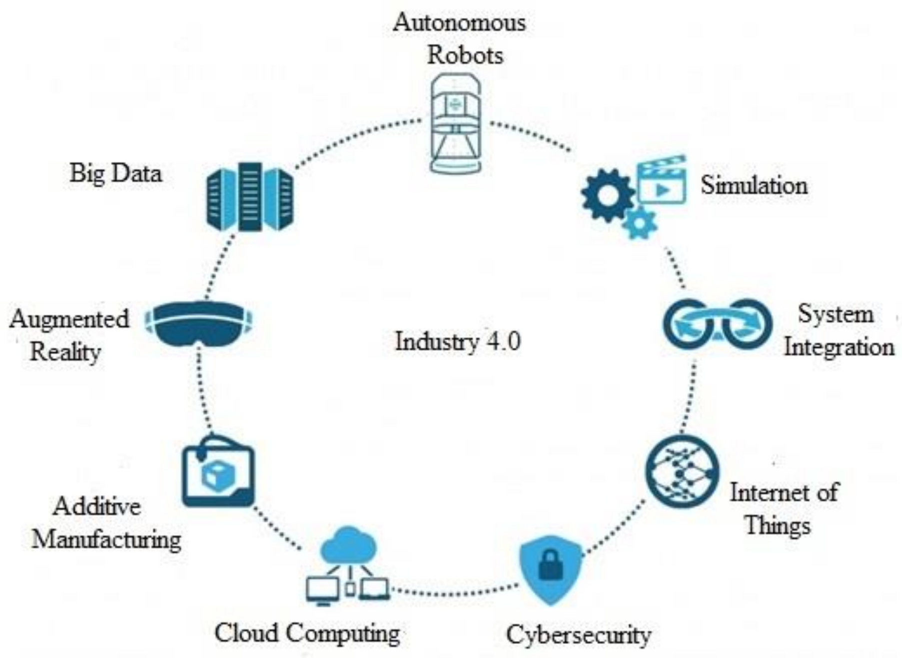

Figure 1. Pillars of Industry 4.0
Source: Adapted from Russmann et al. (2015)

The set of technologies capable of promoting the process of digitization of organizations is known as enabling technologies for Industry 4.0, and there is no consensus on all of these technologies. In a report by the Boston Consulting Group, Russmann et al. (2015) listed a total of nine technologies that present themselves as enabling tools for the development of Industry 4.0, as shown in Figure 1.

2.2 Civil Construction

Although it is responsible for approximately 6% of the world's gross domestic product, the construction industry lags behind other economic sectors in the adoption of technological trends, since most construction processes are still carried out in an artisanal way, executed by manual tools, basic management and low technology (LA RIVERA et al. , 2020).

Despite its relevant role in increasing the population's quality of life, through the comfort and well-being provided by different physical spaces, the construction sector is characterized by low productivity indicators, constant delays in the completion of projects and, mainly, by its costs overruns (OESTERREICH & TEUTEBERG, 2016).

La Rivera et al. (2020) point out that the sector's poor performance is a result of the fragmentation of the supply chain, in addition to the existence of multiple participants with different and unconnected views when acting in different phases, and many repetitive tasks performed in a linear fashion. The authors also point out that, unlike other industrial sectors, it is not possible to have total control of the physical production environment, because of several internal and external variables, and because each final product is unique and built in open spaces with little possibility of control.

Similarly, Oesterreich and Teuteberg (2016) explain some of the causes for the delay observed in the sector:

> Complexity: construction projects have many related processes and sub -processes , in addition to the large number of actors involved (architects, engineers, contractors, subcontractors, suppliers and customers) in different phases and locations.
> Uncertainty: the peculiarities and differences of environments of each construction are responsible for the absence of complete specifications of construction processes and uniformity of materials and workmanship, resulting in an unpredictable environment.
> Corporate culture: the sector is known for its rigid and change-resistant management culture. (p. 123)

According to Pastetti et al. (2018) civil construction can be defined as a custom engineering industry, which means that each final product, that is, each work is practically unique and a type of prototype. Each product is designed in its own time according to the specific needs of each customer.

Despite resistance to change, some strategies from other industries were introduced in the sector. Since the 1940s, prefabrication and modularization of buildings and complex components have been used to improve the construction process. However, due to technical limitations, prefabricated elements are often do not fully satisfy project needs, which may explain their restricted use until today (PASETTI et al., 2018).

Despite the technological backwardness of the construction sector, some areas are the focus of innovations, such as the study of new materials and lighter and more resistant structural systems. However, these innovations have a low use of information and communication technologies, continuing the use of conventional machines and equipment with a still semi-artisanal approach to project implementation (LA RIVERA et al., 2020).

In the managerial aspect, some project management actions have been observed in recent years in the construction industry to improve levels of productivity and efficiency. According to Yeganeh et al. (2019) it is worth pointing out lean construction, a methodology aiming at promoting continuous improvements in construction companies, minimizing losses and enhancing the value of the final product through clear planning and controls.

For Pastetti et al. (2018) the biggest challenge for the construction industry today is to improve productivity levels, compared to other areas, by reducing waste of resources and improving the efficiency of supply chains. These actions are capable of reducing socioeconomic costs, reducing environmental impacts and even improving the final quality of the works.

There is today a great attention to greater efficiency in the use of natural resources and clean industrial activities and concerns with the environment. Thus, according to Mhaske et al. (2017), an adequate management of the waste generated will make construction activities more sustainable, as well as more competitive and profitable.

2.3 I 4.0 innovations in Civil Construction

The construction industry has always been recognized for being more resistant to change and the adoption of new technologies compared to other sectors such as aerospace and automotive. Around the world, there is a reluctance of construction companies to invest and implement new technologies.

As it is an extremely fragmented sector and formed mostly by small and medium-sized companies, there is a great limitation of resources destined to the development and adoption of innovations, thus, currently only a small portion of the companies in the area are able to operate and benefit from the latest technological tools (DALLASEGA et al., 2018).

The transformation observed by the civil construction sector can also be called Construction 4.0, in analogy to the more popular term Industry 4.0. In its 2015 report, the European construction Industry Federation uses the term Construction 4.0 to refer to the digitization of the construction industry. Similarly, Forgues et al. (2019) define the term as the introduction of Industry 4.0 principles in civil construction.

According to Oesterreich and Teuteberg (2016) Construction 4.0 is the set of interdisciplinary technologies that enable digitization, automation and integration of all phases and value chain of the construction process. For La Rivera et al. (2020), despite the diversity of meanings and lack of a standard, there is a consensus that the term Construction 4.0 corresponds to the application of Industry 4.0 in the construction sector, representing the wide digitization of this area. According to Chen et al. (2018) automation in civil construction is still not representative enough to attest to the increase in productivity, but preliminary tests and successful experiences in other areas are strong evidence for its development.

To achieve success in adopting technologies, some actions must be taken by companies in the field. Comprehensive mapping of workflows is essential to enable the integration and transition between people, data and project information, in addition to measuring the success of the implemented technologies (HOSSAIN & NADEEM, 2019).

Another expected change in the workforce, provided by digitalization, is the refinement of the responsibilities and attributions of workers, since they will no longer perform dangerous and repetitive tasks, assuming the role of controllers and supervisors of technologies. Thus, human workers will be responsible for technological management, performing specialized activities and risk-free (SOTO et al., 2018).

There are some key technologies, for example Building Information Modeling (BIM), parametric design techniques, cloud computing and IoT. In some cases Construction 4.0 is used to describe the adoption of information and communication technologies, with BIM being the central tool for the digitization of civil construction (OESTERREICH & TEUTEBERG, 2016; PASETTI et al., 2018).

These technologies are now at different levels of maturity. Some of them, such as BIM and modularization, have become widespread in the market and are widely available. Other technologies, such as additive manufacturing and augmented reality, are still in the formative phase, as their prototypes and applications are still under development for use in the market (OESTERREICH & TEUTEBERG, 2016; PASETTI et al., 2018).

Currently, Building Information modeling (BIM) has been touted as the main tool to provide the digitization of the construction sector. This technology can be detailed as a highly accurate virtual model, throughout all stages of a construction, enabling better control and evaluation than traditional manual methods (LI & YANG, 2017; GAO et al., 2019). Additionally, Eastman et al. (2011) point out that BIM can be considered the result of the improvement of CAD software, allowing lines to be more than mere graphic representations of a project. Given the importance of the topic, in 2018 the Brazilian government implemented the National BIM Dissemination Strategy – BIM BR Strategy. Based on Decrees 9377/2019 and 9983/2019, the BIM BR initiative aims to promote a suitable environment for investment in BIM and its dissemination in the country within a period of 10 years.

Considering that the adoption of new technologies is slow in civil construction, most studies that propose to deal with Construction 4.0 technologies end up focusing mainly on BIM, an already consolidated tool. (HOSSAIN & NADEEM, 2019)

The Internet of Things – IOT emerges as another tool related to Industry 4.0 that can benefit civil construction. Associated with the use of sensors and data processing algorithms, it is possible to monitor the conditions of structural elements, starting from the generation of data from crucial points of the buildings and later sending this information through wireless networks (SONG et al*.,* 2017).

Any type of work needs the supply of inputs and equipment in the correct quantity and time, under penalty of generating great losses. In this sense, based on the IoT, RFID sensors can be used to optimize inventory management, maintaining adequate stock levels and ensuring the correct receipt and storage of materials. Thus, the IoT allows the prevention of losses and waste (MAHMUD et al., 2018).

Although the use of robots in civil construction has been studied since the 1980s, its effective use is still limited, however, there is great expectation that its popularization will occur with the development of more accessible technologies. The field of digital fabrication, also known as dfab, is broad and amenable to many applications. Digital fabrication arises from the combination of digital planning and automation of construction processes, which are typically classified into subtractive, formative or additive methods (SOTO et al., 2018).

Subtractive dfab involves removing materials using electrical, chemical or mechanical processes. In the formative method mechanical forces, heat or steam are applied to reshape or deform a given material. Additive digital fabrication consists of the gradual aggregation of material layer by layer through extrusion, assembly or sandblasting of binding material (SOTO et al., 2018).

In recent years, according to Labonnote et al. (2016), additive digital manufacturing processes, especially 3D printing, have had great development in many industries. With this increase in interest, some research has revealed potential for its large-scale use in construction. The authors define additive dfab as the aggregation of materials through assembly, lamination and extrusion techniques.

Figure 2. Semi-automated mason (SAM)
Source: IReviews (2017).

Figure 3. In situ Manufacturer Robot
Source: InHabitat (2015).

As an example of this technology, one can cite the semi-automated mason (SAM), a robot developed by the company Construction robotics to carry out the laying of bricks as shown in figure 2, and the In situ Fabricator, similar equipment developed by the Federal Institute of Technology in Zurich (ETHZ) as shown in figure 3.
Regarding environmental responsibility included in the concept of Construction 4.0, Stock & Seliger (2016) state that technologies and information services from Industry 4.0 will play a key role in improving the sustainability of construction processes. Connectivity and exchange of information flows will enable the traceability of construction inputs, and will allow the identification of materials that can be reused, increasing the efficiency of recycling processes and making greater use of materials.
The new technologies of Industry 4.0 will allow new ways of dealing with waste management, since from the planning phase it will be possible to identify actions to reduce or eliminate the generation of waste, in contrast to the current practice of waiting for the execution phase and taking decisions only after the generation of waste. The use of BIM, which is a virtual and less expensive environment, together with the availability of information will allow professionals to evaluate different project solutions and their respective execution scenarios in order to reduce waste generation (LU et al., 2017).
In this vein, Cheng & Ma (2013) present a system based on BIM to predict the amounts of waste generated in constructions, allowing companies to identify the critical steps in terms of waste generation and to develop waste management actions for the reuse and recycling.
Despite the benefits presented by the use of this technology, Olugbenga et al. (2018) claim that most waste management tools generated in civil construction still do not have the functionality to operate with the BIM methodology.

2.4 Maturity Model

Business organizations operate in increasingly competitive environments, thus, in a global scenario of fierce competition and full of risks, it is necessary to conduct their internal processes efficiently. That is, it is essential that organizations have support for decision-making that align their processes with their business strategies (SANTOS & COSTA, 2019).

In this sense, maturity models have become important management tools. Maturity models demonstrate how a certain aspect has evolved, allowing organizations to plan actions to achieve the desired results, in addition to providing a simple way to measure their processes (PÖPPELBUSS & RÖGLINGER, 2011).

In general, the term maturity refers to a condition of being complete, ready or perfect. Thus, maturity models, in the view of Pöppelbuss & Röglinger (2011), are reference models that deal with the current state and evolution of maturity in organizations. The authors also point out that maturity models emerged in software engineering and were quickly spread to other areas of knowledge.

The degree of maturity characterizes a state of development within a scale, determined by a starting point (lower degree of development) and an end point (higher degree of development) (BECKER et al., 2009). The same authors also point out that a change to a higher degree can be seen as progress, and each maturity level has its respective characteristics.

Maturity models are a way of evaluating and classifying an organization in relation to a given content (LIN, 2007). Adopted in different areas, such as, for example, quality management, human resources management, among others, the maturity models make it possible to evaluate a state in relation to the achievement of certain objectives, in addition to identifying improvements to be adopted through levels (TIKU et al ., 2007).

Maturity models have been adopted by several other areas, such as supply chain management, project management, Industry 4.0 and many others. Most models are based on two principles: top - bottom approach and bottom-up approach. In the top - bottom approach the maturity levels are first defined and then the corresponding assessment items are determined. In the bottom-up approach, the process occurs in reverse (DE BRUIN et al., 2005).

The main aspects that characterize the maturity models and must be included in their scope are presented in Table 1:

Table 1. Aspects of Maturity Models

ASPECT	DEFINITION
Objective	Maturity assessment of different elements (technologies, processes, resource management, etc.).
Dimension	Specific areas that describe different characteristics of the element under analysis. Dimensions are exhaustive and have different characteristics at each level.
Level	It is particular to the maturity of the element being evaluated. The levels are different from each other.
Maturity Principles	Maturity models can be continuous (evolution at different levels) or complex (fulfillment of all elements at each level).
Evaluation	Qualitative (interviews) or quantitative (Likert scale questionnaires) methods are used .

Source: Adapted from Maier et al. (2012), Roglinger et al. (2013) and De Bruin et al. (2005).

If a model is purely descriptive, its application is a mere evaluation with no indication of measures to improve maturity and performance. On the other hand, prescriptive models indicate how to achieve maturity improvement and positively affect the value of processes. Finally, comparative models allow benchmarking across industries and regions, and compare similar practices across organizations to assess maturity in different industries (DE BRUIN et al., 2005).

2.5 Maturity Models for Construction 4.0

The present paper used the CAPES Periodicals Portal databases to search for the existing Industry 4.0 maturity models for civil construction. Two search axes were adopted based on the researcher's understanding of the subject. The first axis encompasses the maturity model, and the other represents civil construction.

Each of the axes was associated with a set of keywords. The terms " maturity ", " model ", " assessment " and "maturity" make up the first axis, and the words " construction 4.0", " digital construction " and "construction 4.0" were chosen for the second axis. In order to obtain a more representative sample, the research axes were joined, resulting in the combinations shown in Table 8.

Table 2. Keyword combinations

Axis 1	Boolean operator	Axis 2
maturity model	AND	Construction 4.0
maturity model	AND	Digital Construction
Assessment	AND	Construction 4.0
Assessment	AND	Digital Construction
Maturity	AND	Construction 4.0

Source: Authors (2022).

The initial search, carried out in that database in April 2022, and using the five combinations of keywords did not return results, demonstrating the absence of maturity models aimed at Construction 4.0. Thus, it is part of the objective of the present work to propose a new maturity model, totally focused on Industry 4.0 applied to civil construction and to fill the gap that exists today.

2.6 Proposal of Maturity Model

The proposed maturity model of this work was based on the framework of the Comprehensive Research for Maturity Model, developed by Wendler (2012). The author states that for the development of maturity models it is necessary an interactive method composed of three stages (Model Development, Model Application and Model Validation).

Figure 4. Stages for developing a maturity model
Source: De bruin et al. (2005).

Aiming at the operationalization of these steps, the process proposed by De Bruin et al. (2005) was taken as a guide as shown in Figure 4.The process is generic and allows the elaboration and evolution of a descriptive model to a prescriptive one, and also to the comparative model.

Based on existing maturity models related to other industries, the model proposed in this study is composed of four dimensions: Organization, People, Technology and Sustainability.

Table 3. Model Dimensions

Dimension	Features	Sub-dimensions
1. Organization	Development for Industry 4.0 requires continuous improvement, dissemination of innovative culture and resources for new technologies.	1.1 I 4.0 in the Strategy 1.2 Investments in innovation 1.3 Data analysis 1.4 Customization 1.5 Adaptation to change
2 people	The continuous and adequate qualification of the workforce is essential for the digital transformation provided by the intensive use of technologies.	2.1 Training 2.2 Multidisciplinary 2.3 Critical thinking 2.4 Flexibility for changes 2.5 Man-machine interaction
3. Technology	Development of new disruptive and interconnected technologies at all stages of the construction process.	3.1 BIM 3.2 Cybersecurity 3.3 Prefabrication 3.4 Data Management
4. Sustainability	It is not enough just to adopt new technologies, it is necessary to be based on sustainable practices in the economic, social and environmental dimensions.	4.1 Waste management 4.2 Governance 4.3 Ethics and human rights

Source: Authors (2022).

These dimensions were chosen from a detailed comparison of existing models aimed at Industry 4.0, also defining the sub -dimensions presented in Table 3. This information serves as the basis for the research instrument applied in this work.

The maturity levels represent the maturity stage of an organization, where each level has its own denotation and description. The Literature Review identified several maturity models geared towards Industry 4.0 with information about its maturity criteria.

Table 4. Levels of Maturity

Level	Description
0 - Non-existent	There is no implementation of I 4.0 technologies. The organization focuses only on its core operations.
1 - Digitalization	Some practice has already been adopted and there is an I 4.0 vision. Different technologies used in isolation. Predominance of processes without digital interface.
2 - Connectivity	The use of isolated technologies gives way to interconnectivity. Digitally created designs and data tracked through to production.
3 - Visibility	Processes monitored from start to finish with data generation at all stages, not just in individual areas as before. First benefits of I 4.0.
4 - Transparency	Processes are managed quantitatively and their performances are statistically monitored. This level usually occurs concurrently with the use of ERP systems.
5 - Adaptability	Full integration between technologies. The organization has continuous adaptation and practices fully adherent to I 4.0.

Source: Authors (2022).

For the elaboration of the maturity levels of the proposed model, it was decided to make an adaptation of the maturity levels of the ACATECH model created by Schuh et al. (2017). Thus, the levels were defined as shown in Table 4.

4. Methodology

The techniques used in research procedures need to be directly related to the problem question, in order to obtain the greatest possible amount of data for further analysis. Thus, through a literature review, books and scientific articles related to the subject of the present study were selected. Due to the absence of works on the maturity model of Industry 4.0 focused on the construction sector, maturity models of Industry 4.0 applied to other sectors were used as a reference.

One way to collect data is through survey research. Survey research deals with obtaining data and information based on characteristics and opinions of groups of individuals, through a research instrument, usually a questionnaire. The result obtained, provided that the group is representative of the population, can be extrapolated to the entire universe under study (DIAS, 2019).

For Mineiro (2020), the survey research can be characterized as an investigation whose discovery is only possible through direct investigation with the research subjects. Considering the characteristics of the main means of data collection, a questionnaire was chosen to be the instrument for collecting data and information, as it allows wide replication and greater accuracy of responses, in addition to providing freedom of time for responses of the participants.

Thus, from the literature review, where Industry 4.0 maturity models aimed at other sectors were listed, it was possible to prepare the proposed questionnaire to assess the status quo of the construction sector in relation to 4.0 technologies.

The questionnaire, composed of closed questions and in the form of a structured interview, required one answer for each question based on an adapted Likert-type scale , where level 0 corresponds to low or non-existent level of implementation, and the last level 5 represents full adherence to the application of Industry 4.0 concepts.

The Likert scale, created by Rensis Likert , is a type of scale with psychometric responses that is widely used in questionnaires, such as in opinion polls, where participants indicate their level of agreement with a statement based on previously established levels (BERMUDES et al. , 2016).

It is noteworthy that the questionnaires were directed to those responsible for each company, and the answers collected form a data entry for the radar graphs that represent the level of maturity of the participants in question.

The questionnaire applied in the present work contains twenty-three closed questions, with the possibility of answers according to the adaptation of the Likert scale. These questions were grouped into the four dimensions established in this study: Technology, Organization, People and Sustainability.

The companies selected to participate in this study are located in the city of Manaus, all operating in the civil construction sector and with some level of familiarity with Industry 4.0 technologies.

Before the application of the questionnaires, the researcher contacted the participating companies by telephone to verify the degree of knowledge of the topic on screen and if they were interested in participating in the research. The companies provided the e-mail and contact details of their employees who were responsible for completing the questionnaire. Participants were allowed to validate the questions present in the questionnaire, with no reported adjustment to be made.

Aiming at analyzing the answers to the questionnaire, the adapted Likert scale was assigned a scoring system that starts at level 0 and ends at level 5. At level 0, a status of non-existence of adoption of 4.0 practices and technologies is imposed, while level 5 corresponds to the full use and integration of these 4.0 practices and technologies.

For the graphic representation and in a two-dimensional way, the chosen form was the geometric method known as radar chart created by Masaaki Miyamoto and published by Albach & Moerke (1987). The radar chart is an original procedure and shows an important improvement for management control, being the most suitable way for the demonstration and comparison of performance evaluations in industries and organizations.

5. Results

A total of seven different companies successfully completed the questionnaire and the summary of their responses is listed on table 5, which shows the difference in results of different companies of the same industry. The results correspond to the average of their answers to the questions of each dimension.

Table 5. Average result to each Dimension

Dimension	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7
Technology	3,25	1,13	1,63	0,38	2,75	1,25	1,38
Organization	3,6	1,6	1,6	1,8	1,4	1	1
People	3,2	0,8	1,8	1	2,2	1	1,2
Sustainability	4,5	2,83	1,83	1,33	3,33	2,83	2,67

Source: Authors (2022).

From the results of Table 5 it is possible to see that one participant (company 1) has a better performance in every dimension, while company 4 has the lowest results.

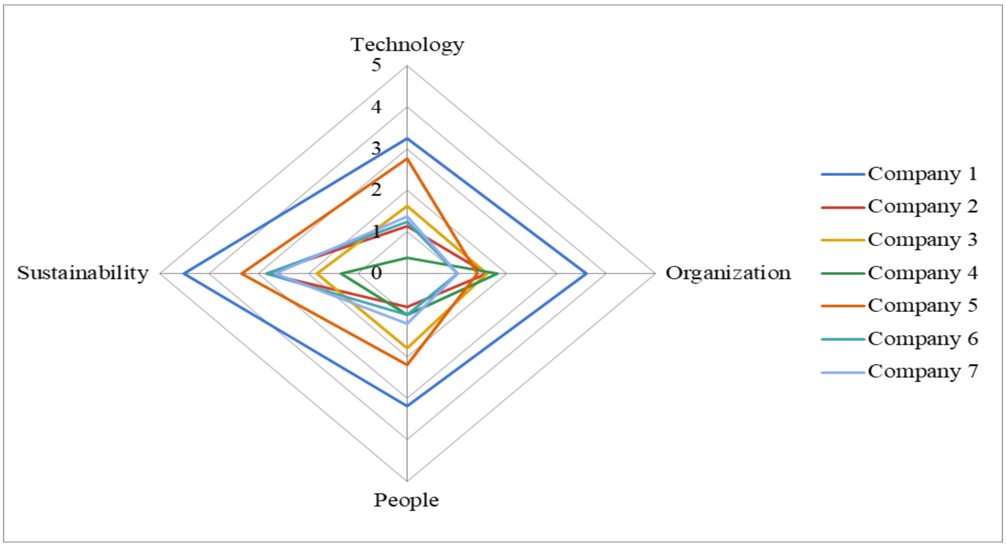

Figure 5. Radar chart comparing results
Source: Authors (2022).

The radar chart presented in Figure 5 allows a better visual comparison of the results, where it is clear that overall the companies had the highest grades on the Sustainability dimension, while the People dimension had the lowest levels.

Table 6. Maturity level of participants

Company	Maturity Level
1	4
2	2
3	2
4	1
5	3
6	2
7	2

Source: Authors (2022).

Considering the individual results collected in all four dimensions it was possible to determine the final maturity level of each participant. Table 6 presents the final results and as previously noted, company 1 has the highest level of maturity on the proposed maturity model, while company 4 had the lowest overall result. Company 1 can be considered a small enterprise since it has less than 20 employees and it is focused on commercial constructions. Its result puts it on maturity level 4 (Transparency) where processes are managed quantitatively and their performances are statistically monitored.

On the other hand, company 4 reached level 1 (Digitalization) on the proposed maturity level where some practice have already been adopted and there is an I 4.0 vision, different technologies used in isolation and there is predominance of processes without digital interface.

5. Conclusion

Industry 4.0 is still an evolving topic in the literature and in the field of construction. Therefore, the number of scientific publications is still low compared to other mature topics, both in engineering and manufacturing. The concepts and technologies discussed in this context are of great relevance to businesses and, in the medium and long term, can significantly change the level of competition between companies and even in entire value chains. Therefore, it is important that companies are prepared for major changes and transformations in business environments and that they have practical and robust tools available to assess maturity in the implementation of concepts and technologies related to the context of Industry 4.0.

The literature review shows that the implementation of Industry 4.0 in manufacturing companies requires a broad and in-depth view, not exclusively focused on system improvements, such as software and hardware in the manufacturing environment, also bringing a new strategic orientation to the business, generating the development of workforce competencies, adapting current business models, developing new products and services for the new volatile demands and their functionalities, and implementing transformative and disruptive technologies that facilitate the process of introducing Industry 4.0 in companies.

In this context, the present work fills an existing research gap by providing a methodologically and theoretically grounded maturity model for the construction sector focused on Industry 4.0 innovations. In this way, the value of the presented model focuses on the combination of scientific rigor, practical relevance and its direct applicability.

This applied work and its proposed model aimed to collaborate with the business environment for the understanding and implementation of the main concepts of Industry 4.0 and its related technologies, having contributed, in this way, also with the academic environment, by bringing a better understanding of this phenomenon. The proposed model was adapted from existing maturity models; based on them, a questionnaire was developed and applied to seven companies with operations in Manaus/Brazil, all related to the civil construction field.

The maturity model proposed in this work is composed of technical resources and specifically related to products and services, factories and processes, management resources related to organizational strategy and culture, workforce qualification and all this, through the use of enabling technologies and transformers.

As a practical result, as shown in section 5 of this work, this model allowed the companies participating in this project to identify their maturity levels related to the concepts of Industry 4.0, through the application of the questionnaire and the compilation of the data obtained.

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