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Construction 4.0: Industry 4.0 enabling technologies applied to improve workplace safety in construction

Construção 4.0: Tecnologias habilitadoras da indústria 4.0 aplicadas para melhoria da segurança do trabalho na construção civil

Construcción 4.0: Tecnologías habilitadoras de la industria 4.0 aplicadas para mejorar la seguridad en el lugar de trabajo en la construcción

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Abstract
Industry 4.0, the new production paradigm, has been arousing the interest of researchers around the world, due to its potential for improvements for companies, however little has been studied of its potential in the construction industry. This paper aims to identify which enabling technologies of Industry 4.0 can be applied to improve job security in civil construction. The methodology adopted was literature review, followed by field study / research with interviews with specialists, to identify the possibility of improving work safety in civil construction, through the technologies of Industry 4.0. The results of this research showed that the main technologies listed were: (1st) 3D printing and drone, (2nd) Augmented Reality and Wearable sensors, (3rd) safety vest, (4th) Virtual Reality, (5th) Bionic exoskeleton, (6th) Building Information Modeling (BIM), Radio Frequency Identification (RFID), helmet with sensors and smart helmets, (7th) Internet of Things (IoT) and finally, (8th) concrete mixer truck. The theoretical and practical contribution of this work is given by the presentation of technologies from Industry 4.0 that can maximize work safety in the construction industry, mitigating accidents at work, thus collaborating for the management of technology and innovation.
Keywords: Enabling technologies; Construction; Industry 4.0; Job security.

Resumo
A Indústria 4.0, o novo paradigma de produção, provoca o interesse de pesquisadores ao redor do mundo, pelo seu potencial de melhorias para as empresas, contudo pouco têm sido os estudos do seu potencial na indústria da construção civil. Este artigo tem por objetivo identificar tecnologias habilitadoras da Indústria 4.0, que possam ser aplicadas para melhoraria da segurança do trabalho na construção civil. A metodologia adotada foi a revisão da literatura, seguida de pesquisa/estudo de campo com entrevista a especialistas, para identificação da possibilidade de melhoria da segurança do trabalho na construção civil, através das tecnologias da Indústria 4.0. Em ordem de importância, as principais tecnologias identificadas foram: (1º) impressão 3D e drone, (2º) Realidade Aumentada e Sensores vestíveis, (3º) colete de segurança com sensores, (4º) Realidade Virtual, (5º) Exoesqueleto Biônico, (6º) Modelagem de Informações da Construção (BIM), Identificação por radiofrequência (RFID), capacete com sensores e capacetes inteligente, (7º) Internet das coisas (IoT) e por fim, (8º) caminhão betoneira. A contribuição teórica e prática deste trabalho se dá pela apresentação de tecnologias da Indústria 4.0 que podem maximizar a segurança do trabalho na indústria da construção civil, mitigando os acidentes de trabalho, colaborando assim para a gestão da tecnologia e inovação.
Palavras-chave: Tecnologias habilitadoras; Construção civil; Indústria 4.0; Segurança do trabalho.

Resumen
Industria 4.0, el nuevo paradigma productivo, despierta el interés de investigadores de todo el mundo, por su potencial de mejora para las empresas, sin embargo, se han realizado pocos estudios de su potencial en la industria de la construcción civil. Este artículo tiene como objetivo identificar tecnologías habilitadoras para la Industria 4.0 que se pueden aplicar para mejorar la seguridad laboral en la construcción civil. La metodología adoptada fue una revisión de la literatura, seguida de una investigación / estudio de campo con entrevistas a expertos, para identificar la posibilidad de mejorar la seguridad laboral en la construcción civil, a través de las tecnologías de Industria 4.0. En orden de importancia, las principales tecnologías identificadas fueron: (1º) impresión 3D y drones, (2º) Realidad Aumentada y sensores portátiles, (3º) chaleco de seguridad con sensores, (4º) Realidad Virtual, (5º) Exoesqueleto Biónico, (6º) Modelado de Información de Construcción (BIM), Identificación por radiofrecuencia (RFID), casco con sensores y cascos inteligentes, (7º) Internet de las cosas (IoT) y finalmente, (8º) camión hormigonera. El aporte teórico y práctico de este trabajo viene dado por la presentación de tecnologías Industria 4.0 que pueden maximizar la seguridad laboral en la industria de la construcción, mitigando los accidentes laborales, contribuyendo así a la gestión de la tecnología y la innovación.
Palabras clave: Tecnologías facilitadoras; Construcción civil; Industria 4.0; Seguridad del trabajo.

1. Introduction

The civil construction industry represents for Brazil one of the business sectors with the greatest absorption of labor, as it is one of the greatest economic powers, with high generation of employment opportunities (Takahashi et al., 2012). Civil construction is an industry that has a large number of accidents and comprises several particularities that differ from the various industrial areas, and it is essential that studies and research are developed aimed at worker safety and health (Peinado, 2019).

Of the sectors with the highest recorded accident rates across the country, in the ranking of occupations that cause accidents with workers incapacity, civil construction ranks first (Associação Nacional de Medicina do Trabalho, 2019). Silva (2015) states that in the civil construction sector, the accidents that arise are worrying, because when they do happen, the consequences are more profound, and can lead to death. Therefore, a study in the area to verify the risks involving workers needs to be carried out at the construction site based on the development and implementation of safety rules that are in fact effective (Silva, 2015).

According to Bridi et al (2013) and Mariano (2008), the work accident rates in the civil construction sector are the highest when compared to other industrial sectors and this is due to the existing resistance in the use of safety equipment and failures in handling them. For Silva (2015) and Colombo (2009), many work accidents and risks in civil construction arise as a result of the lack of knowledge on the part of the worker, delays that end up generating a rush to deliver the work within the deadline agreed with the client, and for lack of observance / lack of proper planning and/or improvisation. These factors turn the construction site into an aggressive environment that is vulnerable to the occurrence of work accidents.

Additionally, one can point out as factors that lead to accidents in civil construction: disproportionately short construction completion time; little or no skilled labor, resulting in high staff turnover; exposure to risks, and execution of activities under unfavorable weather conditions (Brusius, 2010; Silva, 2015). According to Peinado (2019), there is a diversity of regulatory standards, if all were properly implemented, as a result we would have improvements in the safety and health conditions of all workers in the work environment.

Civil construction, according to Medeiros and Rodrigues (2009), and Silva (2015), is a field in which great attention is required when the subject involves safety, quality management and respect for the environment. According to Farah (1993) and Silva (2015), each accident risk condition must be known in advance so that preventive actions can be taken. Thus, everyone involved in the design of the work must provide solutions for the protection of workers through details and specifications, raising awareness, demonstrating and promoting health and safety, in addition to constant inspection. In addition, safety conditions are precarious due to the diversity of activities carried out on construction sites, which increase workers' exposure to risks (Oliveira & Serra, 2017).

According to the study developed by PwC Global (PricewaterhouseCoopers) in 2016, the absence of digital culture and specific training was identified as the biggest challenge faced by engineering and construction companies worldwide in the implementation of Industry 4.0 concepts (Coteaqui, 2017).

Industry 4.0 makes it possible to offer individual customized products, but in the same way as if it were mass production (Acatech, 2013; De Souza, Bezerra, Bresciani & da Silva, 2021). In Brazil, this concept is still maturing and according to the National Confederation of Industry (CNI, 2016), the low growth of this evolution is an obstacle to its use in this country.

Existing Industry 4.0 technologies are starting to be used in civil engineering in developed countries; according to Portugal (2016), even in small construction projects, integration and digitization offer great benefits in reducing failures, increasing efficiency and productivity. In a survey with most Brazilian industries, only 48% of them use at least one digital technology, this percentage increases to 63% in large companies and drops to 25% in small companies (CNI, 2016).

Under the term Industry 4.0 within civil construction, promising possibilities emerge for high-performance production processes based, for example, on digital and cyber-physical systems. However, the construction industry is lagging behind in adapting these ideas and still faces serious productivity deficits (Schimanski et al., 2019).

Industry 4.0 would provide greater gains, flexibility, agility, productive efficiency and constant improvements in the distribution process with greater dynamism (Gilliand & Wenzy, 2012). It brings a series of technological evolutions that allow industries to produce more, in less time, with less cost and with more quality, mainly thanks to industrial automation, the Internet of Things (IoT) and Big Data (Schwab, 2016).

The investment in employee development is justified by the advent of Industry 4.0, which goes beyond innovative technologies, also including the change in the profile of workers, moving from manual to intellectual work and requiring companies to invest in employee training (Aires, Moreira, & Freire, 2017), while improving safety at work.

Given the relevance that life represents, work safety should be a point of relevant studies, however in researching academic databases, it was noted a lack of bibliographic references on Industry 4.0 technologies that can be applied to improve work safety in civil construction, a research gap that this work seeks to fill.

2. Theoretical Reference

It follows the theoretical framework, covering Industry 4.0, Construction 4.0 and accidents in civil construction.

2.1 Industry 4.0

The First Industrial Revolution (Industry 1.0) took place with the mechanization of the means of production, the use of water and steam, at the end of the 18th century (Simon, 2013). The second stage of industrial revolutions, known as the Second Industrial Revolution (Industry 2.0), took place in the 19th century, and was characterized by the intensive use of electricity and mass production through the division of labor (LASI et al., 2014). With the introduction of automation and digitization, through electronics and IT systems from 1969, the Third Industrial Revolution (Industry 3.0) emerged (Kusma & Chiroli, 2020).

The Fourth Industrial Revolution (Industry 4.0) is based on the use of the Internet as an infrastructure and interconnected Cyber-Physical Systems (Kersten, 2014; Cardoso, 2019). The term Fourth Industrial Revolution is currently recurrent, as for many specialists this is in a moment of transition, surpassing the Third Industrial Revolution and entering a new cycle of technological development (Dalenogare et al., 2018; dos Santos, Ruggero, & da Silva, 2021; Gloria Jr., dos Reis, 2021; Ivale, da Silva, & Nääs, 2021; Morais, Costa Neto, dos Santos, Cardoso Jr., & Sacomano, 2020; Schwab, 2016)

2.2 Construction 4.0

In recent years, the growing use of new technologies has allowed the digitization, automation and integration of construction processes in all its phases in its value chain, impacting the construction sector (Oesterreich & Teuteberg, 2016). This entire trend can be referred to as Construction 4.0 (Oesterreich & Teuteberg, 2016). In practice, Construction 4.0 does not only correspond to the use of new or existing technologies, as its application in the field of construction is wide and complex. The Construction 4.0 concept implies a broad and profound transformation of the project management processes of construction companies through the use and exploitation of data collected in real time using new or existing technologies for decision-making purposes (Dallasega et al., 2018).

Today, Building Information Modeling (BIM) is considered one of the central technologies of importance for the digitization of the construction and manufacturing environment (Dallasega et al., 2018; Santos & Piacente, 2021). According to Gerbert et al., (2016), Oesterreich and Teuteberg, (2016), and Steel et al., (2010), BIM can be considered the main feature of Construction 4.0.

Although the integrated BIM model has been a central driving force in the emergence of Industry 4.0 in the construction field, current trends include the emergence of several non-integrated technological solutions (Danjou et al., 2020). Edirisinghe (2019) classifies existing research related to the development of sensor technologies for construction sites based on the different stages of the technology development process, enabling the basic principles of civil construction to be facilitated by this technology. The application areas are mainly focused on: construction phase, augmented reality, model-based visualization of construction information, labor and supply chain tracking, safety management, mobile equipment tracking and on schedules (Edirisinghe, 2019).

2.3 Work accidents in construction

The Union of Workers in the Civil Construction Industries of São Paulo (SINTRACON-SP, 2017) conducted a survey with 659 construction workers in the state, concluding that the main causes of accidents are: lack of attention, non-use of Personal Protective Equipment (PPE), lack of inspection in the workplace and obsolete equipment. In civil construction, the number of accidents is twice the average for other work activities (SINTRACON-SP, 2017).

Occupational health and safety are of paramount importance in a work, but there is a weakening of research in this area (Filgueiras, 2015). The NR-18 regulatory standard is the specific standard for the Brazilian construction industry, and in this case, it meets the issues of the Civil Construction Industry (ICC). Some standards are related to NR-18, as they deal with occupational safety and health in the construction industry in general.

Carvalho (2017) states that the main types of accidents are: falls from heights, cuts and lacerations, RSI (repetitive strain injuries), constant exposure to loud sounds and stings of insects and poisonous animals, accidents that this research seeks to find ways to elimination/mitigation, through the use of Industry 4.0 technologies.

2.3.1 Risks arising from civil construction works

According to Sienge (2019), there are several risks arising from the civil construction works:

● Allergies and respiratory problems (occur due to lack of use of gloves and masks);

● Scaffolding (lack of adequate protection according to NR to avoid accidents);

● Lack of attention and disorganization at the construction site (the construction site requires a lot of concentration and focus from employees);

● Rocker arm (lack of adequate protection according to NR to avoid accidents, due to lack of connection of the seat belt to a fixed place independent of the structure of the rocker arm);

● Electric shocks (electrical installations must be carried out by a qualified professional, with all the necessary safety equipment);

● Dermatosis (cement, mortar and others caused by contacts without the use of gloves);

● Exposure to foreign bodies (insects and other animals);

● Lack of signaling of the beds with the use of signs, barriers, zebra tapes and other signaling methods;

● Falls of materials (usual on construction sites, which can cause serious accidents);

● Falls from the "work at heights" level (which can lead to fatal accidents);

● Use of tools and machines without adequate protection.

2.3.2 Risks due to construction

According to Sienge (2019), the risks due to construction are:

● Access to the work;

● Delay in drawings and project instructions;

● Accidents at work (by workers or at the construction site – collisions, fires, etc.);

● Low professional qualification in most of the workers on site;

● Cost of tests, tests and samples;

● Geological and geotechnical conditions of the work site;

● Damage to people or property;

● Availability of resources and materials;

● High turnover of people;

● Lack of procedures and training;

● Greater individual contact of workers with civil construction equipment and tools;

● Changes at work;

● Lack of project details provided by the owner;

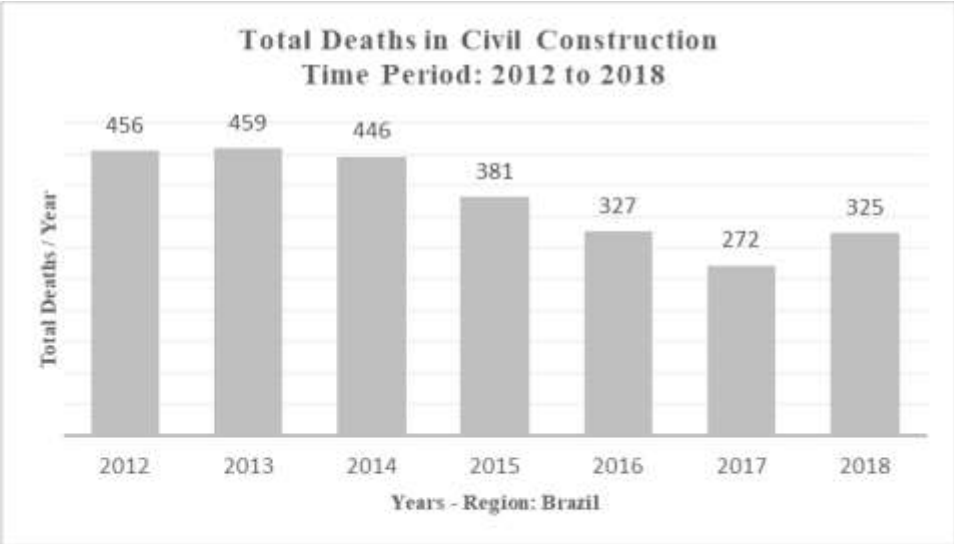
● Defective design;

● Carrying out work activities under weather conditions such as strong winds or rain.

Between 2017 and 2018 there were 97,000 work accidents in civil construction, according to data from the Observatório Digital de Saúde e Segurança do Trabalho [Digital Observatory for Health and Safety at Work] (SmartLab, 2020), which totaled more than 4.4 million accidents in Brazil. In this same period, the number of accidents with deaths totaled 31,900 accidents in Brazil, with civil construction recording 2,666 deaths.

In the period from 2012 to 2018 there was an average of 381 fatal accidents at work in civil construction, according to data from the Observatório Digital de Saúde e Segurança do Trabalho (SmartLab, 2020). Figure 1 below shows the numbers of deaths in civil construction, according to the Statistical Yearbook of Work Accidents - AEAT (AEAT, 2020).

Figure 1 - Total deaths between the years 2012 to 2018 in civil construction.



Source: AEAT (2020).

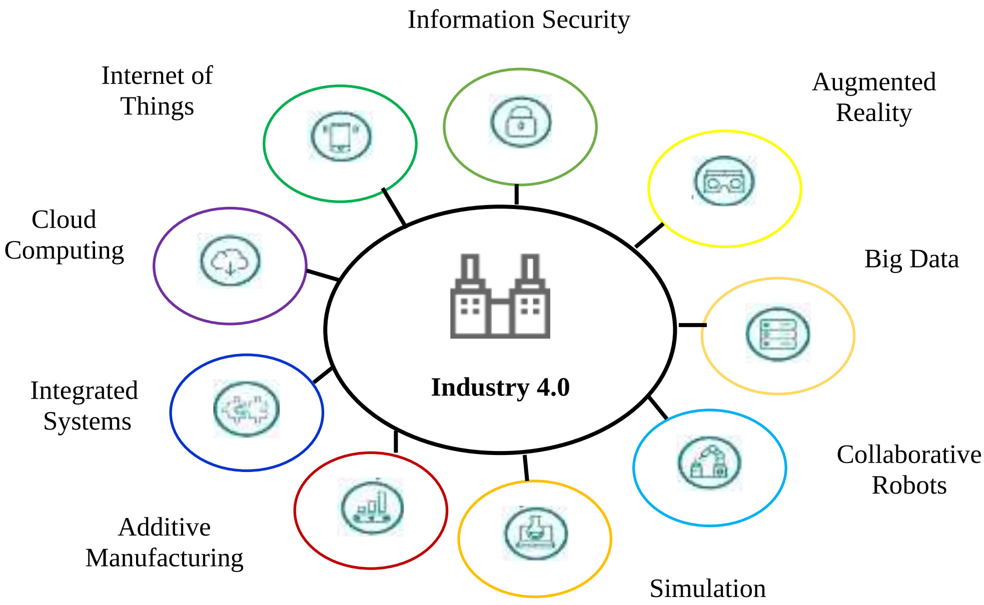
According to the most updated data up to February 2020, available at the AEAT in 2017, there were about 12,651 cases of workers who could not return or returned with some limitations to work, and about 1,000 of these cases occurred in civil construction.

According to the data available (SmartLab, 2020), all the analyzes of occupational accidents that were carried out based on the information provided in the CAT allow us to identify the causative agents, the types of injuries, the most important occupational diseases and the parts of the body that are hit hardest. In a more critical view of the work environment, which are more common in civil construction, it can be concluded that the main types of work accidents in Brazil could have been avoided, especially at construction sites with more effective Health and Safety management of Labor (SST).

2.3.3 Industry 4.0 Enabling Technologies for Workplace Safety

According to Estévez (2016) there are nine technologies associated with Industry 4.0., as illustrated in Figure 2.

Figure 2 - Basic principles of Industry 4.0 (9 pillars).



Source: Adapted from Endeavor (2017).

Data from the Brazilian Chamber of Construction Industry – CBIC (2018) cite as examples of paradigm shifts related to Industry 4.0 the digital sharing of information, digital production (3D printing), process automation and data collection by sensors. Among the technologies of Industry 4.0, there are the Internet of Things (IoT), artificial intelligence (AI), additive manufacturing, augmented reality, Big Data analysis and BIM, being the BIM already applied with relevant impact on construction.

With the Internet of Things (IoT), job security gains the ability to improve itself through remote technology and other mechanisms. The progress of equipment / machines aimed at civil construction enables the use of operations of this kind to avoid exposing workers to risks.

Virtual Reality (VR) is a set of hardware, which can include headphones, computers, sensitive gloves, glasses and others, to give the user the feeling of a reality that is not present in the place, it is only virtual (Sacomano et al., 2018).

Augmented Reality (AR) is a technology that allows us to superimpose elements that are not found there on our vision of the real world, that is, virtual (Sacomano et al., 2018).

The Concrete Mixer Truck Connected is not simply a truck connected to the internet, but a concrete mixer with sensors, used to monitor activities and send data for analysis by companies (Exame, 2020).

In addition, another possibility to make the environment less dangerous is the use of Wearables, which are models of tools granted by the IoT, used as part of the professional's clothing. Examples of these wearable technologies, that is, technologies that the user wears, are the Daqri Smart Helmet, capable of displaying in the user's field of vision 3D projections with information and details of the work, based on the developed BIM project, as shown in Figure 3.

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Figure 3 - Helmet with sensors.

Source: Daqri (Engibim, 2019).

Wearable technology is recent in Brazil; however, it guarantees prosperous results in civil construction. According to North American studies, this technological innovation can increase well-being in the workplace by 3.5% and productivity by 8.5%. In the USA, companies have already installed smart sensors in employee suits to gain greater security.

There are also helmets with smart glasses, or smart glasses that allow the user to quickly access their field of vision: manuals, instructions or even remote support, while keeping their hands free to focus on the tasks being developed (Oesterreich & Teutebrg, 2016), as in Figure 4.

Figure 4 - Helmet vision with smart glasses: constructive details are shown, which are only in the design.

Source: Daqri (Engibim, 2019).

Wearable sensors are devices installed in uniforms and Personal Protective Equipment (PPE) of workers to support the execution of activities. Numerous companies, especially in the United States, have been working intensively in recent years to make this technology model more varied and accessible.

Inserting the sensors into the existing clothing of construction workers is more practical than having them use another device. Figure 5 shows a safety vest with sensors.

Figure 5 - Safety vest with sensors.

Source: Planservice (2020).

Being able to lift heavy loads with less physical effort is the greatest achievement of the bionic exoskeleton suits. Through them, civil construction professionals reduce the risk of suffering injuries when carrying weight (Fiep, 2020). Figure 6 shows an example of the exoskeleton application in a civil construction work.

Figure 6 - Bionic exoskeleton.

Source: Hyundai (2020).

The construction industry has followed the developments in 3D Printing techniques starting to apply them on a larger scale.

3D Printing, also called additive manufacturing, consists of the deposition of layers of materials, for example mortar or concrete, which overlap each other and thus constitute the desired product (Volpato & Carvalho, 2017), shown in Figure 7. With its use, workers are removed from manual activities of greater danger existing on construction sites.

Figure 7 - 3D printing in construction.

Source: WordPress (2015).

Drones in civil construction are true allies, as they can offer greater flexibility and significantly reduce risks to the safety of professionals, safeguarding them from the obligation to go to places of difficult access (Hilfert & König, 2016). Figure 8 shows inspection application.

Figure 8 - Drones in construction.

Source: Globaltec (2020).

RFID tags, Radio-frequency identification, as the tags glued to the windshield of vehicles to pass through toll stations, without stopping, can be used to track materials, equipment and workers (Gerbert et al., 2016). Figure 9 shows the RFID system components.

Figure 9 - RFID system components.

Source: Adapted from Oliveira e Serra (2017).

Giretti et al. (2009) carried out an experiment dedicated to the management of safety and health at construction sites using new communication technologies, powered by an RFID identification system. The implemented system emitted danger warning signals when the worker approached the region with the greatest risk of accident.

For this work, with the purpose of improving work safety in civil construction, the BIM 8D is more specific for providing simulation for safety and accident prevention (latest dimension), which aims to provide information that allows identifying in advance which problems and risks related to worker safety can occur. Table 1 below shows the enabling technologies object of this study.

Table 1 - Enabling technologies focus of this research.

Industry 4.0 enabling technologies	References
BIM	Gerbert et al. (2016), Oesterreich and Teuteberg (2016), Santos and Piacente (2021); Steel et al. (2010)
Concrete-mixer truck	Exame (2020)
3D Printing	Volpato and Carvalho (2017)
RFID – Radio-Frequency Identification	Gerbert et al. (2016); Giretti et al. (2009
Internet of Things (IoT)	Schwab (2016)
Helmet with sensors and smart	Engibim (2019)
Safety vest with sensors	Planservice (2020)
Bionic exoskeleton	Hyundai (2020)
Drones	Hilfert and König (2016)
Augmented reality (AR)	Edirisinghe (2019)
Virtual reality (VR)	Sacomano et al. (2018)
Wearable sensors	Osterreich and Teuteberg (2016)

Source: Elaborated by the authors (2021).

3. Methodology

The adopted methodology was bibliographic research, based on scientific papers and specialized literature, to identify the technologies, followed by research / field study with interviews with specialists, which are characterized by the direct interrogation of people whose behavior one wants to know, without any type of intervention (Gil, 2008).

For the bibliographical research of scientific papers, the Scopus and Web of Science databases were used. The following keywords were used: “Industry 4.0”, Construction OR Building and (“Work safety” OR safety). The surveys were conducted in English and Portuguese, with the aim of finding global results, enabling a comprehensive view of technologies being researched around the world.

The Scopus and Web of Science databases were used, because they are considered the largest in terms of peer-reviewed scientific papers. In order to guarantee the timeliness of the results, the year filter was applied in the survey, to focus on the period from 2014 onwards. The results are shown in Table 2 below.

Table 2 - Paper search results.

Industry 4.0 Technologies in Work Safety in Construction			
Research phases	Search string	Papers (Nr.)	
		Scopus	Web of Science
1st	Construction OR Building	878,069	993,653
2nd	“Industry 4.0”	14,935	8,571
3rd	(Construction OR Building) AND “Industry 4.0”	1,172	1,018
4th	(Construction OR Building) AND “Industry 4.0” AND (“work safety OR safety)	87	56

Source: Elaborated by the authors (2021).

The research phases were refinements made, to concentrate on scientific papers adhering to the use of Industry 4.0 technologies applied to work safety in civil construction. Given the volume of papers in the first three phases, the fourth phase was used for refinement, using the following search string: (Construction OR Building) AND "Industry 4.0" AND (work safety OR safety), reaching a total of 143 scientific papers. Excluding duplicate papers in these databases, 87 papers were reached, whose abstracts were read, 42 papers were selected, which were then read in full. From this analysis, 12 papers were selected that served as the basis for this study.

Additionally, research was carried out in electronic magazines and specialized websites, taking care to request authorization for the dissemination and use of the images from each author / company of the selected technologies.

The data collection techniques used in this study were: (1) questionnaire, a means that is intended to raise the information written by the individuals surveyed (Severino, 2013), when specialists were asked to assess the degree of relevance of these technologies , for the improvement of work safety in civil construction, it was used a questionnaire with a 5-point Likert scale, ranging from 1 - totally disagree to 5 - totally agree, followed by (2) interview, technique for collecting information directly with individuals surveyed (Severino, 2013), with a semi-structured questionnaire, when participants were asked to talk about each of the technologies, in order to assess their level of knowledge about the researched subject. The answers were recorded and then transcribed for analysis. Table 3 presents the statements of the questionnaire.

Table 3 – Questionnaire statements.

Statements
1) BIM technology improves safety conditions at work in civil construction.
2) Concrete mixer truck technology improves safety conditions at work in civil construction.
3) 3D printer technology improves safety conditions at work in civil construction.
4) Radio Frequency Identification (RFID) technology improves safety conditions at work in civil construction.
5) Internet of Things (IoT) technology improves safety conditions at work in civil construction.
6) Helmet technology with sensors improves safety conditions at work in civil construction.
7) Safety vest technology with sensors improves safety conditions at work in civil construction.
8) Smart helmets technology improves safety conditions at work in civil construction.
9) Bionic exoskeleton technology improves safety conditions at work in civil construction.
10) Virtual reality technology improves safety conditions at work in civil construction.
11) Augmented reality technology improves safety conditions at work in civil construction.
12) Drone technology improves safety conditions at work in civil construction.
13) Wearable sensor technology improves safety conditions at work in civil construction.

Source: Elaborated by the authors (2021).

4. Results and Discussion

Eight specialists were interviewed in person, despite the COVID-19 pandemic, all with a degree in civil engineering, among them, two Masters and two Doctors in Engineering, these representing half of the sample. Two specialists were specialized in occupational safety (respondents A and H), four specialized in civil construction (respondents B, C, D and E) and two specialized in Industry 4.0 (F and G). Specialists in occupational safety and in civil construction informed that they are familiar with Industry 4.0, so that the interview can be done.

Regarding the experience of the specialists, only one had a year of experience in the role as a specialist in civil construction, and the others had at least 5 years of experience as specialists. In this there were 2 specialists in civil construction with 37 and 48 years of experience in the function. Respondents A, B and H were from the Paraná region, three of these eight (37.5%), and respondents C, D, E, F and G worked in the region of São Paulo, five of these eight (62.5%).

Respondents B and C worked in a public company comprising 25% of the sample and respondents A, D, E, F, G and H worked in a private company, making up 75% of the sample. Respondents A, E, F, G and H worked in small companies (62.5%) and respondents B, C and D worked in medium sized companies (37.5%). In relation to the year of foundation or the company where the specialists have worked, there was great variation from 1967 to the oldest and the most recent in 2020.

The methodology adopted was the analysis of the mean and the Coefficient of Variation (CV), according to Contador et al. (2020), for classification of technologies.

Coefficient of Variation (CV) is an important and widely used measure of dispersion, used to compare the relative variability of two or more populations (Schiano-Lomoriello et al., 2020).

The Coefficient of Variation (CV) is given by the following formula:

$$CV = \frac{S}{\bar{x}}$$

Where S = sample standard deviation and $\bar{x}$ = mean of the Likert scale values of each respondent's answer regarding each enabling technology adopted for the questionnaire.

The following level of agreement was used as shown in Table 4:

Table 4 - Coefficient of Variation (CV) – Level of dispersion.

Coefficient of Variation (CV)	Dispersion level
$CV \leq 25\%$	Low dispersion (high agreement among respondents)
$25\% < CV \leq 50\%$	Median dispersion (median agreement among respondents)
$CV > 50\%$	High dispersion (low agreement among respondents)

Source: Elaborated by the authors (2021).

As a result of the interviews with specialists, the following classification was obtained:

1st) 3D printing and drone, with the maximum average (5) and with unanimous convergence of opinions (CV = 0%).

1.1) 3D Printing – "*With the increase in use, technology tends to have its cost reduced, being more attractive, so we could explore its full potential. More controlled constructions and fewer accidents*" (Specialist B).

"*It offers countless possibilities, including the creation of specific parts to entire buildings and houses, allows professionals in the area to do much more in less time, with higher quality, it provides a reduction in labor and safety expenses, thus allowing for fewer failure and waste rates*" (Specialist D).

1.2) Drone – "*With drones, we can see services where (before) we could not reach" (Specialist D).*

"The use of drones in civil construction is already a practice that is taking place in Brazilian and worldwide construction, some large construction companies are able to track the worker inside the construction site and verify the correct execution of the task" (Specialist F).

2) Augmented Reality and wearable sensors, which had a high average (4.7) and high agreement among respondents (CV = 10%).

2.1) Augmented reality - "*Augmented reality is also important in the interactivity with the user, allowing him / her to visualize in a real and interactive way how the project will look" (Specialist A) "It has to gain scale, to be more accessible and become viable. It would certainly avoid many accidents*" (Specialist B).

2.2) Wearable sensors – "*The use of wearable sensors is very important, mainly in the aspect of worker safety and productivity solution within the work. It allows managers to map the location on the construction site and measure, in real time, the degree of workers' fatigue*" (Specialist F).

3) Safety vest with sensors, also with high average (4.7) and high agreement of respondents (CV = 15%).

3.1) Safety vest with sensors – "*Allows the verification of the location of employees, enabling better allocation of human resources in the work, improving safety*" (Specialist C).

4) Virtual reality, equally with high average (4.6) and high agreement of respondents (CV=16%).

4.1) Virtual Reality – "*The Virtual Reality System can provide engineers with a complete view of the rotation and translation axes, which facilitates the identification of problems in a work. It can be used from project planning to construction management and presentation to the client*." (Specialist A). "*It optimizes the work, previews, possible changes... Excellent*!" (Specialist H).

5) Bionic exoskeleton, with relevant average (4.5) and high agreement of respondents (CV=17%).

5.1) Bionic exoskeleton - "*The use of the bionic exoskeleton in civil construction is quite viable, mainly to ensure the comfort, health and safety of the worker in assisting in stressful tasks and in the activity of picking up heavy loads and handling them within the construction site, in addition to enabling greater worker productivity".* (Specialist G).

6) BIM, RFID, helmet with sensors and smart helmet that had an expressive average (4.5), but with agreement bordering on the median among experts (CV=21%).

6.1) BIM - "*One of the biggest problems within the construction site is the lack of coordination in the hierarchy because of the outsourcing of services within the work, (there are) problems with compatibility in the different areas, qualified labor and use of PPE; in this respect it would greatly help its application*" (Specialist G).

6.2) RFID - "*For civil construction, RFID is being successfully implemented in access control, proximity warning systems, for tracking materials, in production control, in their storage and in their location of materials, so as in the maintenance of buildings, providing great benefits, such as better organization of the work, as well as the real-time control of processes and materials, which generates a great reduction in work accidents on the work site*." (Specialist D).

6.3) Helmet with sensors - "*The use of helmets with sensors is quite viable in civil construction for greater gains to avoid accidents, with real monitoring of workers, with information on everything that is happening with it, in addition to (this) provides greater productivity to the services performed by the worker*" (Specialist F).

6.4) Smart helmet – "*It allows for better organization of the work, verification of the work situation and real-time monitoring of the work*" (Specialist C).

7) Internet of Things (IoT), with a significant mean (4.3), however with the agreement tending to the median among experts (CV=21%).

7.1) Internet of Things (IoT) – "*The use of the Internet of Things is very viable for civil construction. It can even facilitate the monitoring of PPE's, as well as control the physical conditions of employees, and can optimize their productivity*" (Specialist G).

8) Concrete mixer truck - which had the lowest average (4) and median agreement tending to low among specialists (CV=38%).

8.1) Concrete Mixer Truck – "*The use of the connected concrete mixer truck can greatly contribute to the control of concrete, delivery time, the time it arrives (monitoring) and for tests with higher quality*" (Specialist F). "*I don't see much value in this equipment directly "connected" to civil construction. In addition to the cost for its implementation, which most concrete manufacturing companies are not interested in investing in, even knowing that with this technology it is possible to* *estimate the precise arrival time of the concrete mixer, making it possible to optimize processes and reduce losses*" (Specialist A).

5. Conclusion

The general objective of this study was to identify enabling technologies for Industry 4.0, which can be applied to improve work safety in civil construction.

The civil construction industry is one of the sectors with the highest rates of work accidents. In this way, they directly impact the activities of the work, as well as interfere with the quality of life of workers who expose themselves to unnecessary risks due to lack of guidance and knowledge, or even the omission of those responsible for the execution and supervision of the work.

It is important to note that the conditions exposed to construction workers, such as risks of falls, noise, excessive heat, repetitive strain, lack of personal protective equipment (PPE) and recklessness during work, in addition to ignorance of the standard and regulations, which should be followed by the professional, can cause serious work accidents. Types of accidents that most result in fatalities in civil construction works can result from different causes. The literature mentions the strong resistance to the introduction of new techniques and applications in the civil construction industry, mainly because it is a very traditional industry.

Research was carried out with specialists in civil construction, occupational safety and Industry 4.0 who work in private and public companies, consultants and in public and private universities to analyze the applicability of these enabling technologies of Industry 4.0 in the field, to improve work safety.

The main technologies selected with respect to work safety according to the survey follow in order of importance:

1st) 3D printing and drone; 2nd) Augmented Reality and wearable sensors; 3rd) Safety vest with sensors; 4th) Virtual Reality; 5th) Bionic exoskeleton; 6th) BIM, RFID, helmet with sensors and smart helmets; 7th) Internet of Things (IoT); and 8th) Concrete mixer truck.

The contribution of this work is given by the presentation of Industry 4.0 technologies that can maximize work safety in the construction industry, mitigating work accidents, contributing to the management of technology and innovation.

As a limitation, the small number of respondents, eight, does not allow generalizations of the applications of these technologies, however they point in a direction in this sense. For future work, it is suggested to expand this research with more specialists, if possible, from other states of the federation and also from other countries.

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