Work evolution and safety and health at work in Industry 4.0 / Industry 5.0

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Abstract. Industrial evolution is the most important part of society's development. Technological advances have led to essential changes in the evolution of industries, leading to the appearance of the 4 industrial revolutions. It is also important to emphasize that the evolution of occupational health and safety regulations has always followed the revolutionary developments in the industry. Technological progress, innovation, change and streamlining of technology, products and processes, have had a number of real consequences (positive or negative) on the safety and health of workers. All this provided the impetus to identify and implement reliable and sustainable solutions to ensure their safety. The purpose of this study is to present a brief review of the characteristic elements of the 4 industrial revolutions that have taken place over the years and to identify and propose recommendations to be implemented to ensure (maintain or improve) safety and health of workers in the context of the transition to Industry 4.0 / Industry 5.0.

1 Introduction

Industrial evolution is the most important part of society's development. All over the world, industrial development started from the 18th century. All the industrial revolutions that have taken place over the years have been triggered and driven by transformative technological advances and have led to essential changes in the way industries operate, but also generated important social changes [1,2].

The purpose of this study is to present a brief review of the characteristic elements of the 4 industrial revolutions that have taken place and to identify and propose recommendations to be implemented in order to maintain or improve the safety and health of workers in the context of the transition to Industry 4.0 / Industry 5.0 and towards a circular economy. These 2 concepts - the circular economy and Industry 4.0 - although they are different, they are complementary, interconnected and aim to improve the way organizations and the whole economy work, in a sustainable way: through an efficient and optimal use of resources through the implementation of advanced technologies and monitoring and control systems; through more efficient management of resources and better planning of recycling and reuse of materials; through an improvement in collaboration and

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cooperation between manufacturers, suppliers and other stakeholders, etc. Also, the transition to a circular economy model also impacts on the safety and health of workers, which can bring both benefits and challenges for workers, which is why it is essential to correctly identify and manage the risks associated with new processes and technologies.

For this study, the following objectives were established:
1. Making a synthesis of the work evolution from Industry 1.0 to Industry 4.0 / Industry 5.0.
2. Proposing recommendations to be implemented to maintain or improve worker safety and health in the context of the transition to Industry 4.0 / Industry 5.0 and towards a circular economy - following the analysis of new and emerging risks, as well as the challenges and opportunities that the integration of digital solutions implies.

The paper begins with a presentation of our research methodology, followed by the presentation of the results obtained from the analysis of data and scientific literature on the characteristic elements of industrial revolutions and the evolution of occupational safety and health of workers in this context. The last section presents our conclusions from this study, as well as the current limitations of research in this direction.

2 Methodology

For this study, the necessary data were obtained by using the Scopus interdisciplinary database, also taking into account the fact that this database is most frequently used by researchers to conduct systematic analyzes of the literature, to carry out previous scientometric and bibliometric analyzes.

To identify relevant studies, the following document selection criteria were applied:
1. Search for the selected keywords, in the article title, abstract and keywords, according to the following criteria:
   ("safety" OR "occupational safety and health" OR “occupational health” OR “occupational safety”) AND ("industry 1.0" OR "industry 2.0" OR "industry 3.0" OR “industry 4.0” OR “industry 5.0”) OR (“work evolution”)  
2. Type of documents: articles, conference paper, book chapter, review, conference review, open access  
3. The search period: 2010-2023; Language: English.

Following the application of this selection, a number of 565 publications were identified. Later, based on the analysis of the title of the documents and the abstract, a number of 23 publications were selected and included in the analysis in the present study – Figure 1.

Fig. 1. The method of selecting the documents included in the study.
3 Results and discussion

The results obtained from this study, which has a theoretical approach, were presented in the following in the form of a synthesis of the evolution of work, which includes the characteristic elements of the 4 industrial revolutions that took place over the years and that produced a series of fundamental changes within society - the main technical achievements and the main industries that developed in each time period – Figure 2.

![Characteristics of the four industrial revolutions](image)

**Fig. 2.** Characteristic elements of the four industrial revolutions [1,3,4].

As can also be seen from this graphic presentation, the time interval between two industrial revolutions is getting shorter and shorter, precisely because of increasingly rapid technical changes, so today's revolutions take place gradually, before being fully introduced in all activity sectors [1].

**Industry 1.0** – The first industrial revolution: During this period, the use of water and steam energy in production begins [3]. The Watt steam engine was developed, which led to
several further developments and applications. The use of hydraulic power, steam and the mechanization of production caused important changes in the economy and in transport [5]. Sectors such as the textile industry (the first loom was built in 1784), metallurgy, chemicals, agriculture, transport, mining and other developments developed [4]. The development of the steamship, or (about 100 years later) the steam locomotive, made the transport of people and goods over long distances much easier [3]. During this period, the transition from manual work to the mechanization of production processes was achieved [6]. Small companies developed into large organizations and there was an evolution of entrepreneurial culture as a result of increased efficiency and volume of production (improved production and performance).

Industry 2.0 – The second industrial revolution: Electricity has been used as the primary energy source, but at the same time gas and oil are also used as energy. Computers were developed; they were first introduced in the textile industry, where it led to a series of changes. It was also during this period that the telegraph and the telephone were invented and thus the development of communication technologies began; the radio, the gramophone, photography, cinema appeared [6]. The first assembly line was also installed, standardizing and simplifying the mass manufacturing process even more [3]. The performance of the production process has been increased by using interchangeable components. The extent of technical progress recorded in production has influenced scientific expertise and research, forming organizations, research and development departments. The development of steel production, contributed to the development of railways and their integration into the economy, favoring the development of mass production and trade [6]. Oil-based internal combustion electric motors and car construction also developed and became more widespread. The transition to the mechanization of agriculture is made, in order to replace animal traction and human work, to increase production and productivity. The development of rural factories began, which allowed the movement of goods. The economic situation during this period was quite fluctuating, being influenced by the two world wars, but also by the economic crises that took place ("the great depression" of 1873, the collapse of the stock market in 1929 in the United States, etc.). Progress is also beginning to be made in the field of chemistry, through the development of synthetic dyes, of fertilizers [4].

Industry 3.0 – The third industrial revolution: The development of electricity, the invention and manufacture of a range of electronic devices (transistors, integrated circuits), significantly improved systems and processes, with electronic and IT systems being integrated throughout industry [3,6]. Also, during this period, the aeronautics industry, astronautics, the means of communication (television, video, radio, etc.) are developing. [5]. The automation of the production process and the integration of industrial robots were achieved, which led to the increase of the efficiency of the industrial system and made the critical points in the process safer and more efficient [4]. Globalization of the economy, through the transition of manufacturing operations from developing countries to underdeveloped countries, has led to the need for expanding connectivity requirements.

Industry 4.0 – The fourth industrial revolution: Industrial automation, robotic production, by integrating digital technology, information technology and communications in production processes, with the aim of optimizing production processes, increasing productivity and efficiency, was achieved [7,8]. The networking of all systems has led to the appearance of "cyber-physical manufacturing systems" and thus to "smart factories", which use a network to connect production systems, products and people [6]. In this period, attention is directed towards digitization (the Internet of Things (IoT), cloud computing, Big Data technology, augmented reality (AR) and virtual reality (VR), autonomous robots, exoskeletons, etc.) and technologies based on artificial intelligence (AI) for improving the
efficiency and flexibility of production, these systems being considered favorable elements for achieving the transition towards a sustainable and circular economy [9].

Industry 5.0: The process of innovation and development of digital systems continues: metaverse, virtual reality and holography, IoT systems, Big Data, blockchain, etc. [10]. In this period, precisely because of the development potential of digitalization, connectivity and cyber-physical systems, there is the possibility of economic development, by making products of a higher quality, personalized/individualized services, which involve a lower impact on the environment, a low social impact and at the same time a significant level of welfare for workers [5,10–12]. Thus, the attention is directed to the transition to the circular economy, to the transition from the technological development objectives, to the objectives of increasing the welfare of workers and protecting their fundamental rights. At the same time, industry 5.0 needs to be resilient enough to quickly adapt to geopolitical changes, social tensions, the occurrence of possible natural disasters, climate change, etc.

Technological progress, innovation, change and streamlining of technology, products and processes have had a number of real consequences (positive or negative) on worker safety and health, as this field has evolved over the years with revolutionary developments in the industry. This process of industrial evolution is also reflected in the evolution of regulations and safety standards adopted by organizations, as can be seen in Table 1.

**Table 1.** Synthesis of occupational injury and disease risks, as well as the main existing legal regulations, specific to each stage of industrial evolution.

<table>
<thead>
<tr>
<th>Occupational injury and disease risks</th>
<th>The mode of organization and regulation of prevention and protection activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical risk (mechanical, explosions)</td>
<td>I 1.0 - No specific provisions have been developed to regulate workplace safety; - The formation of labor unions begins, through which workers began to demand safer working conditions; - Governmental organizations have begun to introduce industry-specific regulations.</td>
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<tr>
<td>Ergonomic risks</td>
<td></td>
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<tr>
<td>Chemical risk (gas inhalation)</td>
<td></td>
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<tr>
<td>Biological risk (due to poor working conditions)</td>
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<tr>
<td>Improper microclimate (poor ventilation)</td>
<td></td>
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<tr>
<td>Extended working hours</td>
<td></td>
</tr>
<tr>
<td>Physical risk (mechanical, explosions)</td>
<td>I 2.0 - Preventive measures are implemented in the production processes, based on ensuring the safety and hygiene of workers; - 1919 - the International Labor Organization (ILO) is founded, which has the role of promoting labor rights and improving working conditions globally.</td>
</tr>
<tr>
<td>Ergonomic risks</td>
<td></td>
</tr>
<tr>
<td>Biological risk (viruses, bacteria, from animal waste, infested grains, particles/powders, grain dust in suspension, etc.)</td>
<td></td>
</tr>
<tr>
<td>Chemical risk (pesticides, fertilizers)</td>
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<tr>
<td>&quot;Classic&quot; risks related to the 4 component elements of the work system: executor (e.g. omissions, wrong actions, non-compliance with safety measures), work load (e.g. mental overload), means of production (e.g. mechanical, thermal, electrical, chemical, biological risks) and work environment (e.g. noise, vibrations, microclimate conditions, chemical pollutants)</td>
<td>I 3.0 - 1950-1960 - studies are developed in the field of ergonomics, psychology; - 1970 - the development of national legislations to address aspects related to health and safety at work begins; - 1970 - the Occupational Safety and Health Administration (OSHA) was founded. It sets occupational health and safety standards and regulations, monitors compliance with them and provides guidance and resources on protection against occupational risks. - 1978 - OSHA Training Institute (OTI) was founded, as part of the Occupational Safety and Health Administration (OSHA) in the United States of</td>
</tr>
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5
## Occupational injury and disease risks

<table>
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<tr>
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<tr>
<td>America; - In the 1980s, the first minimum standards are introduced at European level to ensure the protection of workers; - 1987 - safety and health at work is introduced in the European Economic Community treaty (CEE); - 1989 - the “Framework Directive” 89/391/EEC is introduced, which sets out the general principles and requirements for ensuring the health and safety of employees in all aspects related to work; - 1994 - the European Agency for Safety and Health at Work (EU-OSHA) is founded; - 1999 - the standard OHSAS 18001 Occupational Health and Safety Assessment Series was published</td>
</tr>
</tbody>
</table>

## New and emerging risks resulting from the integration of new digital technologies

| Psychosocial risks | 1 |
| Ergonomic risks | 4.0 |
| Physical risks generated by direct human-robot interaction [13] | 5.0 |

As can be seen in the summary presented in Table 1, over the years, the occupational health and safety activity of workers has evolved, as a result of the technological and social advances that have taken place in society. This evolution of regulations was also a natural consequence, as a result of the new and emerging risks that arose as a result of the...
implementation of digital solutions by organizations. Regarding the mechanisms for identification, assessment and control of risks, it is very important to take into account the complexity of the work activity, by analyzing all the component elements of the work system (executor, work load, means/work equipment and working environment).

Legal regulations and worker safety have increased precisely to meet the new needs of the workplace. The development and implementation of regulations in the field of safety and health at work is essential both for ensuring the safety of workers, but also for ensuring the safety of the entire work process. It is important to note that specific developments and regulations may vary by country and region. It is the presence of such a legislative framework that favors the successful implementation of an adequate management of the safety and health of workers [14].

Based on the data synthesized and analyzed in this study, we also developed a set of measures that we recommend to be analyzed, evaluated and taken into account by each organization. These measures address the challenges identified in the context of the transition to Industry 4.0 / Industry 5.0 and which are essential to be able to maintain or improve the safety and health of workers:

- Adapting the existing infrastructure in organizations to facilitate the implementation and standardization of new technologies [11];
- Ergonomic design of workplaces (adaptation of work equipment, worker posture, work load) for the prevention of musculoskeletal disorders;
- Choosing appropriate safety systems and measures to prevent the risks of occupational injury and illness, based on a rigorous identification and assessment of all risks [10,13,15–17]. Considering the fact that the methods for identifying and assessing the risks of occupational injury and illness, the prevention measures, as well as the monitoring and management measures for them are developed based on traditional risks, it is necessary to develop new methods of risk analysis, which should be adapted to the new identified professional risks;
- Promoting a culture of workplace safety through the active involvement of workers in the process of identifying, evaluating and managing the risks of occupational injury and illness specific to workplaces;
- The adoption by organizations of a socio-technical approach to the organization of workers' activity, which facilitates and optimizes the integration of digital technologies [2,18] for example: organizing workplaces so that both technological requirements and workers' needs and skills are taken into account; the active involvement of workers in the decision-making process; developing workers' skills, ensuring balance between professional and personal life, etc.;
- Reviewing and updating policies and procedures in the field of occupational health and safety to reflect new existing conditions [19];
- Developing appropriate policies to ensure the continuous personal and professional development of workers throughout their lives, so that they have the capability to adapt to this new stage of the economy's development: appropriate training on the new technologies and equipment used; training and education programs covering relevant health and safety issues; the development of digital skills; identifying and assessing new skills and training needs of workers: knowledge, skills, abilities (e.g. intuition, creativity, social skills, leadership, communication) etc.) [11,20];
- Identifying and implementing appropriate measures to assure the well-being of employees, an essential aspect for the success and sustainability of organizations: for example, the active involvement of employees in the transition process towards the integration of new digital technologies; providing training and professional development programs in the technologies and skills needed to adapt workers to
the new work environment; promoting a healthy organizational culture, a positive work environment, etc. [7];

- Implementation of programs to monitor workers' health and to identify and adequately address risks associated with environmental conditions [21];

- Implementation of solutions to ensure the security and confidentiality of workers' personal data, especially in the conditions where new digital systems collect and process large amounts of data related to workers: for example, the implementation of appropriate technical and organizational measures, for the effective implementation of the principles of protection of workers' data, according to art. 25 of Regulation (EU) 2016/679 on data protection; informing employees about the type of data collected, the purpose of data collection and processing; employee rights, etc. [7,8,10];

Fig. 3. Aspects to be analyzed to ensure the safety and health of workers in the context of the transition to Industry 4.0 / Industry 5.0.

4 Conclusions

Industry 5.0 is the next stage of industrial evolution and focuses, among other things, on the importance of ensuring the well-being of workers [14]. Research carried out to date has shown that ensuring a high level of welfare and safety and health of workers favorably influences the productivity, associated costs, efficiency and success of the entire industrial system [14]. Also, the studies carried out to date indicate an increasing involvement of employers and workers in improving aspects of their occupational health and safety.

The contribution made by this study consists in proposing a set of measures that we recommend to be evaluated individually and the appropriate measures implemented, with the aim of assuring or improving the safety and health of workers in the context of the transition to Industry 4.0 / Industry 5.0.

Limitations of the research:
1. In the context of the transition to Industry 4.0 / Industry 5.0, precisely due to the great diversity of digital systems available, due to the specific peculiarities of each field of activity, due to the specific activities and tasks carried out by workers, further in-depth studies are necessary, in each field of activity, in order to be able to identify concrete solutions to aspects such as: sustainable development of human resources management (the way of organizing and carrying out the process of responsible recruitment and selection of employees; developing workers' skills; stimulating creativity, digitization skills and their motivation, etc.); strengthening the individual resilience of workers; ensuring worker confidentiality; addressing the identified challenges and risks and maximizing the opportunities, which depends heavily on how the technologies are used, managed and regulated, but this will be the subject of another research study.

2. For this study, the necessary data were obtained by using the Scopus database, but the results obtained may vary in the case of using other databases, for example Web of Science-Core Collection or Google Scholar. Thus, we recommend carrying out additional studies, in which more databases are used to collect the necessary information.

3. In order to identify relevant studies in this field, we recommend applying other document selection criteria, given that the selection of publications depends to a large extent on the search keywords.

Thus, in order to assure the safety and well-being of workers, it is necessary to carry out additional, interdisciplinary, in-depth studies, which analyze the integration of safety and health measures at work in the context of the transition to a circular economy, to Industry 4.0 / Industry 5.0, respectively in the context of the integration digital solutions by organizations.

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