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Analyzing Labor Market Dynamics in Industry 4.0: An Economic and Sociological Bibliometric Study

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Abstract:

Purpose: *The article examines the vast literature on the labour market in the context of Industry 4.0, as well as highlights main contemporary research streams on this issue. This encompasses an examination of the impact of Industry 4.0 on labour markets, including the key technological elements of Industry 4.0 integrated with the labour landscape, as well as identifying opportunities and challenges.*
Design/Methodology/Approach: *The article presents findings from a comprehensive bibliometric analysis which allowed to gather a sample of 3,815 publications until July 2023.*
Findings: *The results show a growing research interest in studies on the labour market and Industry 4.0. Findings reveal the following challenges job preservation; the necessity of retraining employees; occupational safety integration; skill polarization and the increased demand for highly skilled employees.*
Practical Implications: *In contrast, benefits include supporting workers in a production environment; enhancing the effectiveness of the training system; supporting occupational health, safety, productivity and improving ergonomics in the workplace.*
Originality/Value: *The originality of this study lies in a comprehensive examination of the relationship between the labour market and Industry 4.0. What is more, our research is not limited to one discipline as was the case with other studies.*

Keywords: *Bibliometric analysis, big data analysis, Industry 4.0, labour market, machine learning, workplace.*

JEL codes: *C18, C55, J01, J40.*

Paper type: *Research article.*

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1. Introduction

One of the leading research debates in recent years revolves around the changes in the labour market that have occurred in connection with the fourth industrial revolution, which is also known as Industry 4.0. The strategic initiative known as Industry 4.0, introduced by the German government, was publicly announced in 2011 at the Hannover Messe Industriein Germany. Industry 4.0 refers to the following aspects: Internet of Things, 3D printing, artificial intelligence, automation, robotics, quantum computing, etc., (Schwab, 2015), and its main goal is to transform industrial manufacturing through exploitation of new technologies and digitalisation (Rojko, 2017).

The changes in the labour market that have occurred in connection with the fourth industrial revolution concern not only new forms of work, but also employee relations, work organisations, worker behaviours, and personnel management.

The increased focus on Industry 4.0 has raised many challenges and questions about the meaning and impact of this concept in terms of various areas of socio-economic life. The literature on Industry 4.0 has rapidly grown over the last few years indicating that Industry 4.0 has a huge impact on the economies a whole. The emerging technological development, digitalisation, innovation, and other aspects will have an important impact on every economic sector, especially in terms of competitiveness and productivity (Kagermann, 2015).

However, what is more relevant, Industry 4.0 will also lead to many fundamental changes on the labour market and will impact employee's skills development (Pereira and Romero, 2017). These transformations are related, among others, to work environment, working conditions, job profiles, and required work skills (Agolla, 2018; Ing *et al.*, 2019).

While there are several articles on bibliometric analysis related to various aspects of labour market in the context of the fourth industrial revolution, most of the previous bibliometric analyses are focused on single aspects of the labour market (e.g., worker-system interaction by assessing a non-intrusive technology for measuring human eye movements (eye tracking) (Zheng *et al.,* 2022), occupational health and safety (Fargnoli and Lombardi, 2020; Zorzenon *et al.*, 2022), training for Industry 4.0 (Naranjo *et al.,* 2020; Cazeri *et al.,* 2022), flexible job shop scheduling (Mohan *et al.,* 2021), or remote management for employees and employers (Mirakyan and Berezka, 2021). To our best knowledge, there are no studies related to the labour market as a whole and its meaning in the context of Industry 4.0.

Accordingly, the purpose of this paper is to examine the vast literature on the labour market in the context of Industry 4.0, as well as to highlight main contemporary research streams on this issue. The main objective of the paper was to identify the following aspects: the major types of influences of Industry 4.0 on the labour

market; the main technology of Industry 4.0 associated with the labour market; the main opportunities and challenges on the labour market associated with the fourth industrial revolution; the main research areas/themes of the labour market in the context of Industry 4.0.

Our paper also presents several important studies on the impact of Industry 4.0 on the labour market. Additionally, we identify areas that can be potentially analysed in the further research. The following research questions guide the research:

- How did transformations occur in the labour market due to the fourth industrial revolution?
- In which aspects does the Industry 4.0 lead to improvement of working environment conditions?
- What are the key research areas in the literature on the labour market and Industry 4.0?
- What are the main Industry 4.0 technologies that are related to the labour market?
- What are the research gaps in the literature on the labour market and Industry 4.0?

The presented paper is a comprehensive bibliometric study for which the authors collected and selected documents to the analysis, evaluated the degree of study for the topic, as well as identified the key trends and new research areas to investigate labour market in the context of the fourth industrial revolution. This study contributes to the literature through an extensive discussion on the current state of the topic, and the meaning of labour market in the context of the fourth industrial revolution. We suggested issues for further research to open new research avenues.

The originality of this study lies in a comprehensive examination of the relationship between the labour market and Industry 4.0. What is more, our research is not limited to one discipline as was the case with other studies (Brancaccio *et al.,* 2022). Furthermore, most authors (Costa *et al.*, 2019; Chain *et al.*, 2019) analysed only a couple of keywords, whereas we investigated as many as 15,324 keywords (in the second approach) and 35 different important topics in the final approach. Finally, we ensured deeper interpretation of the keyword analysis.

This paper helps to understand what is the contribution of Industry 4.0 technologies to the labour market, as well as the role of employees and employers in the digital area. Our study provides mainly theoretical benefits, as well as a wide view of the current knowledge, and guidelines for future research. Additionally, this study will aid employees and employers by shedding light on the technologies of Industry 4.0 explored in the literature and by explaining the application of these technologies to support health, safety, and well-being of employees, as well as productivity and competitiveness from the employer's perspective.

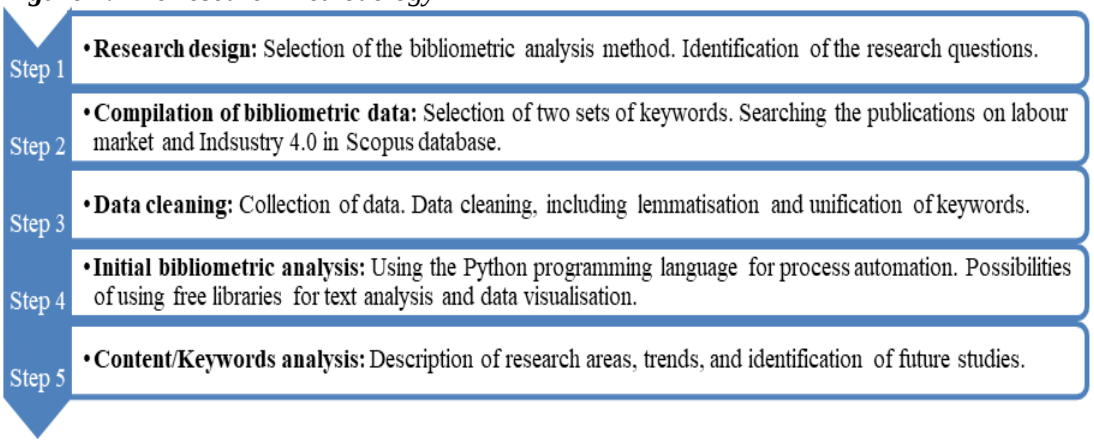
Additionally, this research will help labour market participants, researchers, educators, policymakers and others to deal with the challenges of Industry 4.0 in a more effective manner. The remainder of this article is structured as follows. The second section presents data and methodology. Next, the initial bibliometric results are described. The third section includes keyword analysis and content analysis. In the last section, conclusions are presented and general topics are discussed.

2. Research Methodology

Select Bibliometric analysis is a common and rigorous method for analysing and exploring large amount of scientific data (Zampeta and Chondrokoukis, 2023). The data included in bibliometric analysis tends to be huge (i.e., hundreds, if not thousands of items). It enables to identify emerging areas in a specific field, measures the number of citations and publications, occurrences of keywords and main topics (Donthu *et al.,* 2021). Bibliometric method is currently firmly established as a scientific tool and is used frequently to investigate different scientific and applied fields. What is more, bibliometric analysis lends itself to study various areas of science (Ellegaard and Wallin, 2015).

Zupic's and Čater's approach (2015), which emphasizes that bibliometric analysis should include the following steps: research design, compilation of bibliometric data, analysis and data-cleaning, visualization, and interpretation, was followed. In this study, modern computing power was used to analyse big data elements of articles in order to identify underlying patterns (Qasim, 2017). The research methodology for the study was shown in Figure 1. The first step was the research design. In the step second, a compilation of bibliometric data was carried out. Step third was focused on data cleaning. The fourth step involved initial bibliometric analysis. Finally, the fifth step included the analysis of keywords and findings. The approach used in this study can be also applied to other studies.

Figure 1. *The research methodology*



Source: *Own elaboration.*

2.1 Research Design

Research design was the first step of the bibliometric analysis. As it was mentioned above, the purpose of the study was to examine the vast literature on the labour market in the context of Industry 4.0, as well as to highlight main contemporary research streams on this issue. As the scientific source of data, the Elsevier's Scopus database was chosen. This database is "the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings" (Elsevier Scopus Blog, 2022). In the literature, the Scopus database was recognised as the most used database because it covers larger citation index than Web of Science (Zhao and Strotmann, 2015).

2.2 Compilation of Bibliometric Data

In the second step of the analysis, a search for publications on the labour market and Industry 4.0 (the fourth industrial revolution) was performed using Elsevier's Scopus database. In order to find all substantial and important documents, the query consisted of combination (AND) of two sets of keywords: ("Industry 4.0" or "fourth industrial revolution" or "I 4.0" or "I4.0" or "4IR" or "4th industrial revolution") AND ("labour" or "wage" or "worker" or "workplace" or "workforce" or "employment" or "unemployment" or "employee" or "employer").

The three search filters were set. The first one was the search field. According to the previous bibliometric analysis (Chain *et al.,* 2019; Costa *et al.,* 2019), documents were searched in article title, abstract, and author/indexed keywords of the articles. The second filter was the time scope of the analysis. The time scope of the analysis was from 2011 until July 2023. The starting point of the analysis was the year 2011, when the term Industry 4.0 was introduced by the German government (Klitou *et al.,* 2017). The last filter was related to the document type, language, and subject area. To ensure reliability of the research sources, conference papers, articles and books written in English (in terms of all subject areas) were included in the analysis.

2.3 Data Cleaning

The third step of the study was collection of data. As it was mentioned above, the data was extracted from Scopus database as CSV files. Consequently, 3,815 publications were found, and the oldest document was published in 2013. In order to ensure that the sample includes only relevant publications, the data cleaning was carried out. In order to include only relevant articles in the sample, the following methods were employed: the keyword lemmatisation and unification, and study of interdependencies between keywords.

In the process of compilation of bibliometric data, it was noticed that some studies (Brancaccio *et al.,* 2022) included only the most cited articles. While the study itself did not have this limitation, the impact of number of citations was included in the

analysis. What is more, the number of citations was analysed in terms of both authors and institutions. In addition, the 10 most cited publications in the research area were also studied (see the third section).

2.4 Initial Bibliometric Analysis

In the fourth step of the study, an initial bibliometric analysis was performed based on the sample (3,815 publications). The following aspects were studied: the number of new publications by year, top countries with the largest number of publications, and common publications of authors from the top 25 countries. The top 10 most cited publications were also investigated.

The literature indicates that the choice of visualisation and analysis software belongs to the scholars, whereas each software has its pros and cons (Donthu *et al.*, 2021). One of the most common software programmes used in the literature is VOSviewer (Qasim, 2017). However, this software has some serious limitations in data analysis and in result presentation methods. In order to address this issue, the own algorithms written in Python were prepared, which allowed to conduct a more complex analysis.

The undoubted advantage of using the Python programming language is the possibility to employ free libraries for text analysis and data visualisation. For instance, the WordNetLemmatizer from the Natural Language Toolkit (NLTK) library was used to group together different inflected forms of keywords. NLTK provides interfaces to over 50 corpora and lexical resources (NLTK, 2022). For data visualisation an open source JavaScript library Apache ECharts was used (2022).

2.5 Keywords Analysis and Content Analysis

The last part of the study was keywords analysis and content analysis. The exported files with data about considered publications were processed by the algorithms, which allowed to find and analyse keywords and authors of the publications. In this part of bibliometric analysis, the most popular keywords and their interconnections were analysed. First, the most popular keywords were identified. It enabled the recognition of 35 major research areas and topics. Then, interconnections between those topics were studied in the analysed publications. In the next step, the share of a specific topic in publications in each year was analysed. Thus, the trends of selected articles were also investigated. Finally, areas for future studies were identified.

3. Initial Bibliometric Results

Figure 2 presents the number of new publications by year. As noted, there were 3,815 publications on the labour market in the context of Industry 4.0 published in the years 2011-2023. The first articles was published in 2013. It presented the future

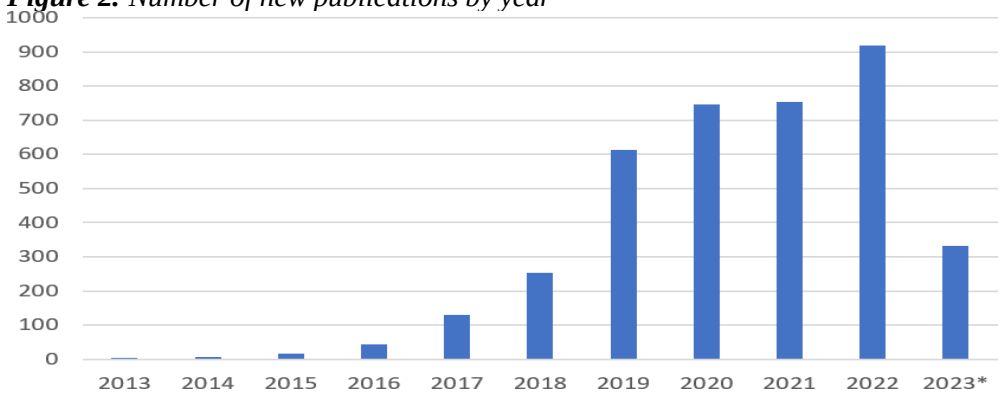
of production work based on the survey among 660 corporate representatives (Spath *et al.*, 2013).

In 2013, the three conference papers were also published. The first one presented the application a virtual numerical control for flexible machining of individualized products by employees (Rehage *et al.*, 2013). The second one was about engineers who interact with complex, computer-aided tools, and use system of computer aided design and manufacturing in their job (Ziesing and Hochstein, 2013). The last one presented the use of the Cyber Physical Assembly System to support interactive work schedules and employees' performances (Dombrowski *et al.*, 2013).

The number of publications has grown over time until 2020. In 2021, the number of publications has decreased, however, it was still high and amounted to 427 publications. In 2022, the number of publications have been increasing and amounted 918 publications.

In 2023 (until July) the number of publication was still high and amounts 331 publications. The findings showed a growing research interest in studies on labour market and Industry 4.0. It also indicated that the research on labour market and Industry 4.0 had been developing year by year.

Figure 2. *Number of new publications by year*

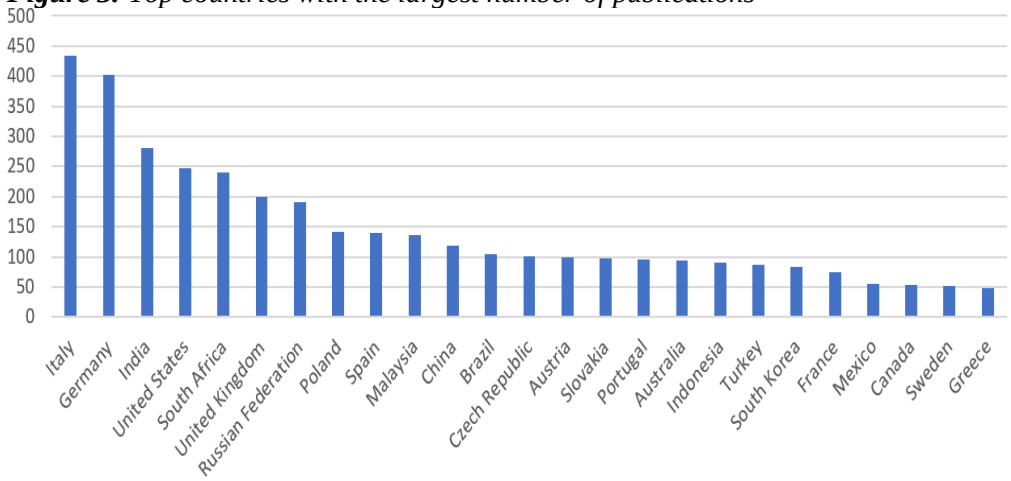


Note: *2023* - until July 2023.*
Source: *Own elaboration based on the Scopus.*

Figure 3 shows countries with the largest number of publications. Only countries with at least 50 publications were shown in this Figure. Italy, Germany, India, the United States, South Africa and the United Kingdom had the highest volume of publications (434, 403, 281, 247, 240 and 200 articles, respectively).

These countries published approximately 48 percentage of the articles included in the sample. The results indicated that these countries predominated in terms of conducted research in the area of publications on labour market and Industry 4.0.

Figure 3. *Top countries with the largest number of publications*



Source: *Own elaboration based on the Scopus.*

In the initial stage, common publications by authors from the top 25 countries were also analysed (Figure 4). The darker the colour, the stronger the connections between countries. If the connection is related to the same country, it means that the number of publications comes from that country. The largest number of common publications came from the United Kingdom (135), the United States (108), Germany (107), Italy (102).

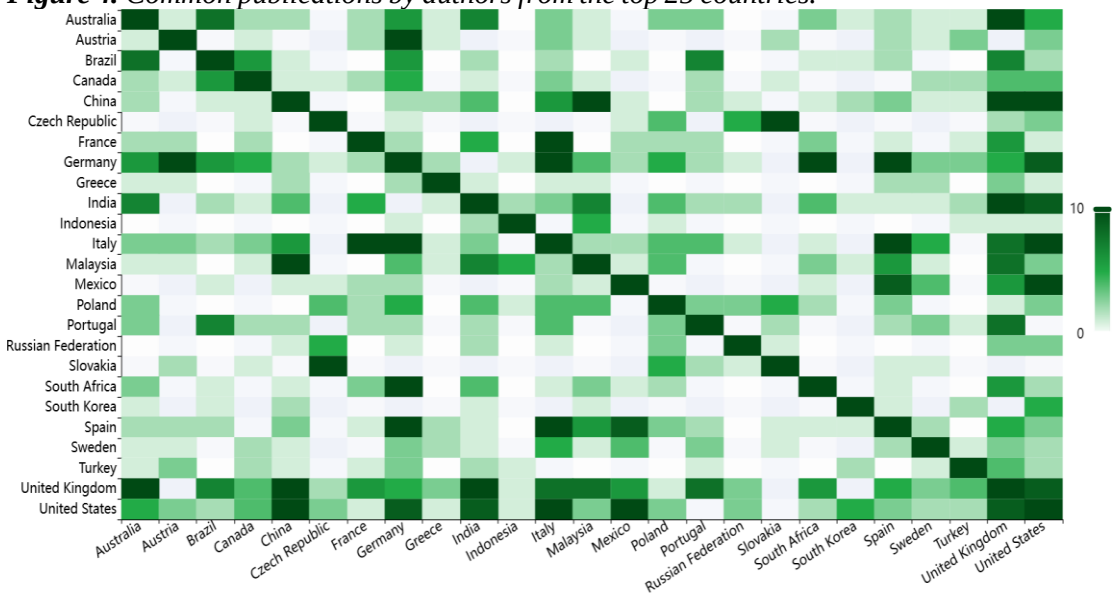
The largest co-authorship was observed between the United Kingdom and India (17 common publications). The same number of common publications was observed between the United States and Italy. A relatively high cooperation was also identified between Australia and the United Kingdom (16 publications), between Austria and Germany (14 publications). This suggested that countries that cooperate with each other can benefit from the exchange of knowledge and experience, as well as from the access to different data sources.

Table 1 presents the top 10 most cited publications in the research area with the number of citations. The most cited article analysed Industry 4.0 in Germany and in China. The main findings indicated that nowadays China is no longer the lowest–cost labour market. What is more, there was an upward trajectory in China in manufacturing capability development, human capital investment and research and development commitment. The important role in strategy Industry 4.0 in China was assigned i.e., train and attract talent, optimize the structure of Chinese industry and achieve green environment and manufacturing (Li, 2018).

The second most cited article studied the technological assistance of workers, changing tasks and demands for the human in the factory and human-machine interactions. The main findings indicated that technological support ensures that employees can realise their full potential, as well as adopt the role of strategic

decision-makers (Gorecky *et al.*, 2014). The third most cited article examined how top executives understand the concept of Industry 4.0, the driving forces for implementing new technologies and the key barriers to Industry 4.0.

Figure 4. *Common publications by authors from the top 25 countries.*



Source: *Own elaboration based on the Scopus, Interactive version on https://data.lewoniewski.info/industry/countries*

This study was based on novel data that were collected from semi-structured interviews with executive members of firms. The main results were as follows: the significant driving forces behind Industry 4.0 included production factors, increase control and possibility of real-time performance measurement; the main barriers of implementation Industry 4.0 in the workplace was organizational resistance at both employee and middle management levels; small and medium-sized companies had lower forces and lower barriers to Industry 4.0 than multinational enterprises, however SMEs had good opportunities to implement new technologies and innovations (Horváth and Szabó, 2019).

Table 1. *Top 10 most cited publications in the research area*

Title	**Reference**	**Cits**
China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0"	Li (2018)	545
Human-machine-interaction in the industry 4.0 era	Gorecky et al. (2014)	522
Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?	Horváth & Szabó (2019)	500
Holistic Approach for Human Resource Management in Industry 4.0	Hecklau et al. (2016)	429

A review of the meanings and the implications of the Industry 4.0 concept	Pereira & Romero (2017)	421
The role and impact of industry 4.0 and the internet of things on the business strategy of the value chain the case of Hungary	Nagy et al. (2018)	326
Requirements for Education and Qualification of People in Industry 4.0	Benešová & Tupa (2017)	305
Privacy-Preserved Data Sharing towards Multiple Parties in Industrial IoTs	Zheng & Cai (2020)	289
Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers	Birkel et al. (2019)	229
Augmented reality in support of Industry 4.0—Implementation challenges and success factors	Masood & Egger (2019)	220

Source: *Own elaboration based on the Scopus.*

The fourth most cited article (Hecklau *et al.*, 2016) analysed employee qualification and competence related to new technologies and processes of Industry 4.0. In this article, authors pointed out that new strategic approaches for holistic human resource management are necessary in companies in the era of Industry 4.0. What is more, they also postulated to increase the level of the staffs' education due to the continuous automation of manufacturing processes.

In their opinion, the main challenge of Industry 4.0 on the labour market is to qualify employees to shift their capacities to workplaces with more complex processes, as well as to ensure the retention of occupations in changing working environments (Hecklau *et al.*, 2016).

On the other hand, Pereira and Romero concentrated on Industry 4.0 concept and contributed for its further understanding about the importance and implications of this technological system. With regard to the impact of Industry 4.0 on the labour market, their findings showed that the automation of tasks leads to the requirement of new skills and competences from workers. According to their analysis, the development of skills among workers was one of the most important factors for the successful implementation of the Industry 4.0 concept. They also pointed out that training will lead to the creation of more jobs than those that will be eliminated.

As a result, new competency areas need to be included in education (Pereira and Romero, 2017). The another significant study aimed to examine how Hungarian companies interpret and understand Industry 4.0, and how they use of Internet of Thing tools in the workplace. In this study, the challenges companies face during adaptation of Industry 4.0 concept were also investigated. This research was based on an online questionnaire and expert interviews. The main results indicated that real-time data sharing and the use of appropriate analytical tools influence positive on overall company performance, cooperation and logistics (Nagy *et al.*, 2018).

The relevant topic in the literature on the labour market and Industry 4.0 was also employee qualifications and competences related to new technologies and processes

of Industry 4.0 (Benešová and Tupa, 2017). The key findings of this study included: some physically demanding positions can be replaced by machines and the process of automation; the key aspect of implementation of Industry 4.0 is retaining existing employees because of their knowledge of the current manufacturing process; the demand for skilled employees in data analysis and in programming will increase as a result of Industry 4.0; these changes will require changes in curricula in tertiary education (Benešová and Tupa, 2017).

Another important topic was the issue of data sharing in Internet of Things systems in industry. Two algorithms for data sharing were developed in this research due to the fact that workers perturb their data before uploading to secure differential privacy. The proposed algorithms for data sharing included privacy preservation, payment, utility and bandwidth consumption. Authors also assessed the effectiveness of the proposed methods (Zheng and Cai, 2020).

The next high cited article addressed the issue risks in the context of Industry 4.0 that is related to the Triple Bottom Line of sustainability. This study was based on a literature review and 14 in-depth expert interviews. Firstly, authors pointed out that the most relevant economic risks involve: threats to existing business models, the potential for misguided investments, as well as increased competition between companies. With regard to ecological risks, the following were identified: an increased waste and energy consumption and other ecological challenges. In turn, technical risks included data security, legal risks related to data ownership related and other IT-related concerns (Birkel *et al.*, 2019).

The last most cited article indicated that industrial augmented reality is a main part of Industry 4.0 initiatives. Thanks to the industrial augmented reality, workers were able to be smoothly integrated into the digital environment. What is more, the performance of the augmented reality system varied in terms of the experience of the employees: lower for trained workers and higher for untrained workers.

Additionally, the capability of being used by an employee for a whole day and the information visualisation had an impact on the readiness of the augmented reality system to successfully support the task. Finally, workers who used the augmented reality system were also a valuable source of input in terms of the issue of ergonomics (Masood and Egger, 2019).

The top 10 most cited publications in the research area also identified the main challenges on the labour market in the era of Industry 4.0. The challenges included: ensuring the retention of jobs in the changing working environment; the need to train employees to shift their capacities to jobs with more complex processes; potential losses resulting from the integration of occupational safety and health into Industry 4.0; potential job losses caused by the new technology; consequences for job activities and qualifications (e.g., “polarisation” of skills); necessity of learning new skills; increased need for highly-skilled employees.

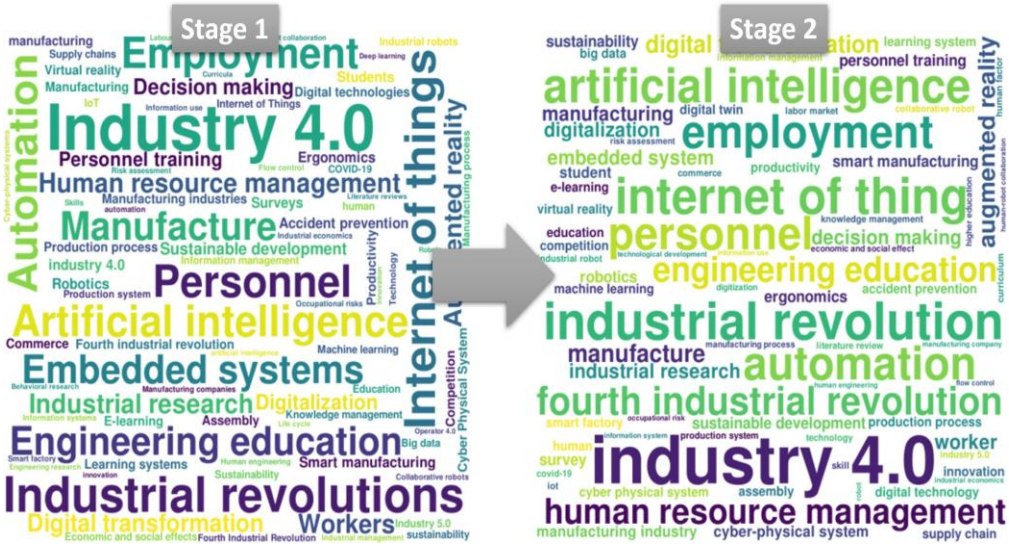
4. The Results of Keywords Analysis and Content Analysis and Discussion

One of the most relevant steps of the bibliometric analysis is a keyword analysis (Munõz-Villamizar et al., 2019). The keyword analysis showed the major topic trends, as well as relations between the keywords. This step was also useful to refine influential research and to understand the research areas. Although the keyword analysis is a very common part of bibliometric analysis, most of the articles (Chain *et al.,* 2019) are limited to presenting the keywords and their networks. In this article, not only the connections between keywords were investigated, but also the share of specific keywords in publications in each year.

4.1 Keywords Analysis before Lemmatisation and Unification

Consequently, in the next step of the study, an analysis of keywords was conducted. Firstly, based on the sample (3,815 documents), 18,797 keywords were identified. Figure 5 (left side) shows the most frequent keywords in the analysed articles. The larger the word, the more frequently the word appears in the analysed articles. However, the first approach was improved, and consequently, lemmatisation, tokenisation, and stop words filtering were performed in the next stage.

Figure 5. *The most popular keywords before lemmatization (stage 1) and after lemmatization (stage 2)*



Source: *Own elaboration based on the Scopus.*

4.2 Keywords Analysis after Lemmatisation and Unification

In order to improve the first approach, in the next step, the NLTK library was used for lemmatisation to group together different inflected forms of a single word (they can be analysed as a single token). Additionally, keywords were simplified with

additional information in parentheses. For example, the keywords "Internet of things (IoT)" and "Internet of things" are considered as the same keyword. Thus, stop words that are insignificant (such as conjunctions: "or", "and") were filtered. The spaCy library was used for lemmatisation to group together different inflected forms of a separate word. Consequently, 8,295 keywords were selected.

Figure 5 (right side) shows the most frequent words in the publications after lemmatisation, tokenisation, stop words filtering, and unification. The analysis of the most frequent words used in the sample (right side of the Figure 5) indicated that the main technologies of Industry 4.0 in the context of labour market include: Internet of Things, artificial intelligence, automation, augmented reality and digitalisation.

Apart from various technologies, the identified keywords included: "personnel", "human resource management", "engineering education", "manufacture", "decision making", "sustainable development", "robotics", "sustainability", "smart manufacturing", "personnel training", "ergonomics", "accident prevention", "productivity", "education". The evidence illustrated that the key terms were related to many aspects of labour market, its participants, and processes. The keywords were also deeply connected with the fields of economics, management, and engineering.

4.3 Unification of the Keywords Based on the Meaning Performed Manually

Observing the frequency of words after lemmatization and unification, it was evident that it is better than in the first approach, but it could be also improved. It was noticed that the list of keywords includes terms that are synonyms (e.g., "Industry 4.0" and "fourth industrial revolution", "e-learning" and "elearning", "augmented reality" and "ar") and words with similar meaning (e.g., "on the job training" and "training on the job").

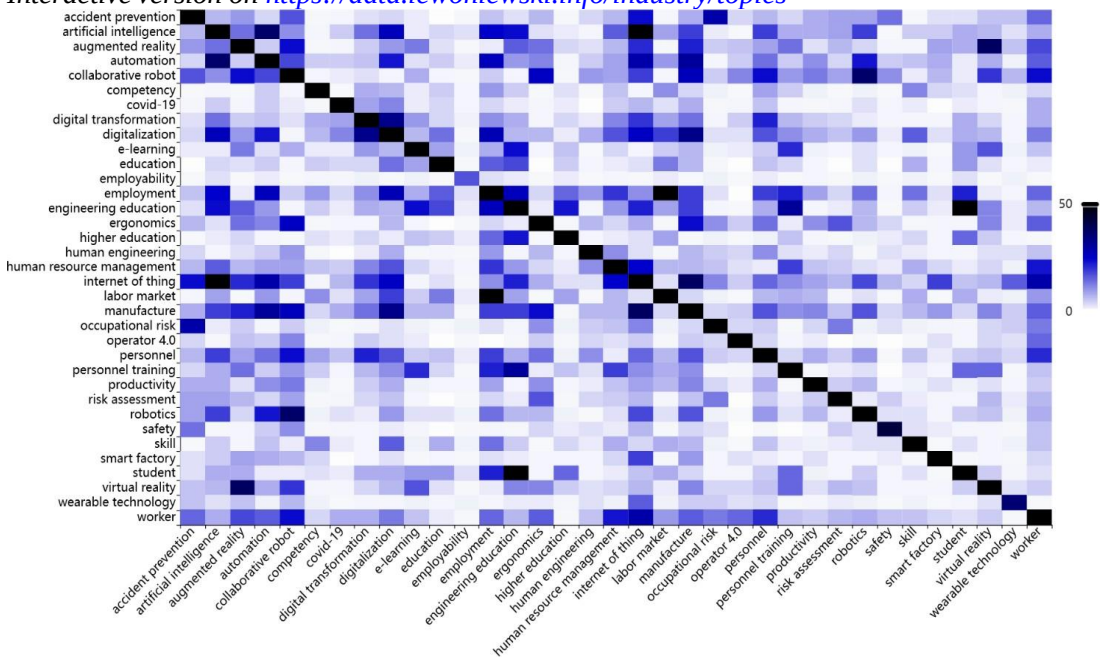
What is more, this problem was observed in other publications. For example, in some articles the particular Figures were not legible and included words that are synonyms (e.g. "iot" and "internet of things") (Sierra-Henao *et al.*, 2020; Nedjwa *et al.*, 2022). It showed that the process of automatisation is not enough in the bibliometric analysis and it may lead to mistakes. Therefore, the decision was made to improve the list of keywords. Thus, in the next step, the list of keywords was analysed in terms of similarity.

Afterwards, the specific words were manually grouped with their synonyms or words with similar meaning. To ensure reliability of the study, the process of manual word grouping was discussed with experts in economics. In addition, due to space limitations and to ensure that Figures will be legible, the 35 most important topics were included in the analysis. Each of the selected topics contains keywords that occur in total at least 20 times in considered publications. In addition, words that

were important only in few years or were very general (e.g. "survey") were excluded.

Figure 6 presents interconnections between topics in the analysed publications. Generally, the number of interconnections was the highest for the following topics: "internet of thing" (485 publications), "employment" (431 publications), "manufacture" (428 publications), "digitalization" (393 publications), "artificial intelligence" (381 publications), "engineering education" (369 publications), "collaborative robot" (367 publications), "automation" (355 publications), "worker" (343 publications), "personnel" (313 publications), "augmented reality" (303 publications), "human resource management" (268 publications), "personnel training" (252 publications), "digital transformation" (246 publications), "virtual reality" (232 publications), "robotics" (230 publications), "accident prevention" (225 publications), "student" (225 publications), "ergonomics" (224 publications), "labor market" (220 publications), "e-learning" (180 publications), "productivity" (155 publications), "education" (153 publications), "risk assessment" (148 publications), "occupational risk" (141 publications), and "skill" (131 publications). The number of interactions for other topics was lower than 130.

Figure 6. *Interconnections between topics in the analysed publications. Interactive version on https://data.lewoniewski.info/industry/topics*



Source: *Own elaboration based on the Scopus.*

In the next step, a deeper study of the most relevant interconnections between topics was carried out, measured as a number of articles. The most frequent interconnections involved the following pairs of topics: "student" and "engineering

education" (58 articles), "internet of thing" and "artificial intelligence" (56 articles), "labour market" and "employment" (51 articles), "virtual reality" and "augumented reality", "internet of thing" and "manufacture" (38 articles, respectively), "robotics" and "collaborative robot", "automation" and "artificial intelligence" (37 articles, respectively), "digital transformation" and "digitalization", "manufacture" and "digitalization" (33 articles, respectively), "personnel training" and "engineering education", "automation" and "manufacture" (31 articles, respectively).

Based on the analysis of interconnections between topics, it can be stated that Industry 4.0 changed the work environment and created a strong demand for training and further education for existing and future workers. Thus, engineering education played an important role in preparing employees for the digital revolution and its consequences.

However, engineering education should be consistent with the requirements of employers. Qualifications and competences of workers and engineering students can be developed in learning factories (Gualtieri *et al.,* 2018; Dreher *et al.,* 2020). The analysis also indicated that education systems should be focused on training engineers of the future and professions that do not exist yet (professionals). There is no doubt that IT skills and information skills are required in the digital era.

However, the research showed that it is also necessary to develop soft skills including: teamwork skills, cognitive skills and flexibility (Valeyeva *et al.,* 2020). Adoption of the Industry 4.0 technologies in companies will lead to the increased demand for highly skilled workers (Benešová and Tupa, 2017).

Other uses of the Industry 4.0 technologies in the workplace were related to adoption of virtual and augmented reality, and process mining in the training system for industrial operators (Roldán *et al.,* 2019; Damiani *et al.,* 2018; Pierdicca *et al.,* 2017). Many authors also claimed that an augmented reality system could support human workers in a changing production environment by visualising relevant information or guiding the user through specific tasks (Paelke, 2014).

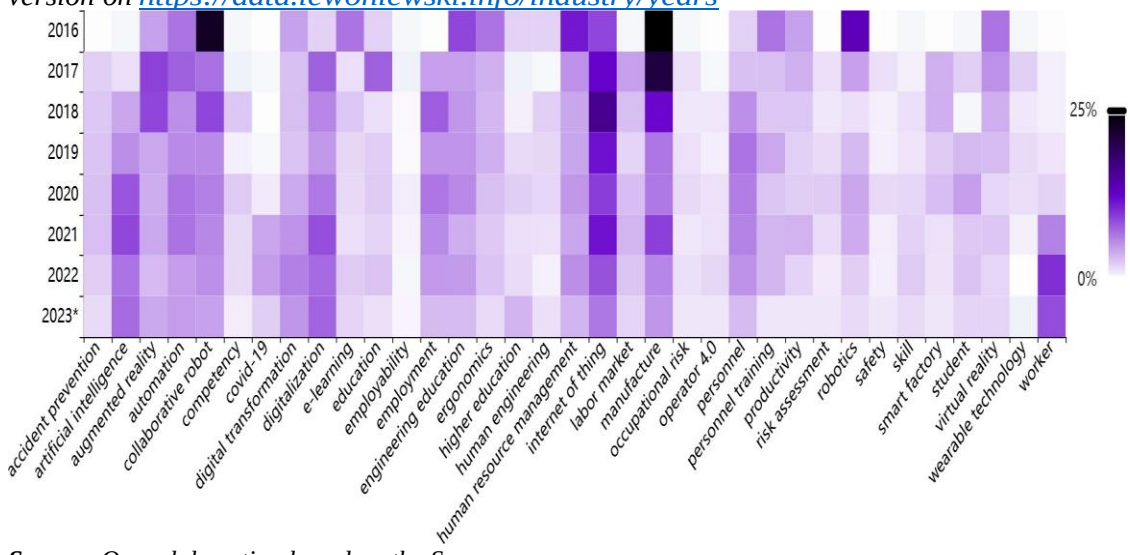
Studies showed that virtual reality-based training system is more effective than the traditional one. It was also evaluated as superior to the traditional training system by most users (Abidi *et al.,* 2019). Many authors (Demir *et al.,* 2019; Khalid *et al.,* 2018; Pérez *et al.,* 2020) also concentrated on the issue of Industry 4.0 and human-robot collaboration. The challenges related to human-robot collaboration involve legal, regulatory, ethical, psychological, social, and ethical issues.

For example, social implications of human-robot collaboration indicated that social interactions between human beings might be limited (Demir *et al.,* 2019). However, studies also showed that robots were perfect substitutes for skilled workers for some repeatable and general tasks (Pérez *et al.,* 2020). Apart from the challenges related to collaborative robots in the workplace from the organisational point of view, the

impact of human-robot collaboration on the worker safety was also widely analysed in the literature (Khalid *et al.*, 2018). On the one hand, Industry 4.0 technologies such as enterprise wearable will support occupational health, safety, and productivity for the Operator 4.0 and could decrease potential occupational risks and support ergonomics (Svertoka *et al.*, 2021). On the other hand, Industry 4.0 may lead to new forms of accidents in the work environment, as well as to overwork or to deterioration of workers' mental health (Min *et al.*, 2019).

Apart from investigating topic interconnections, the share of specific topics in publications in each year was also studied. Figure 7 shows the share of publications with a specific topic in each year. At the beginning of the analysis, the most popular topics included: "manufacture" (27.27 percentage of publications), "collaborative robot" (22.73 percentage of publications) and "robotics" (13.64 percentage of publications). These topics were also relevant in the years following the analysis, however, their share was lower.

Figure 7. *Share of publication with a specific topic in each year. Interactive version on https://data.lewoniewski.info/industry/years*



Source: *Own elaboration based on the Scopus.*

In 2017, the most popular topics included: "manufacture" (20.93 percentage of publications), "internet of thing" (12.4 percentage of publications) and "augmented reality" (9.3 percentage of publications). In 2018, 16.14 percentage of publications included the topic "internet of thing". Next were: "manufacture" (12.2 percentage of publications) and "collaborative robot" (9.06 percentage of publications). Similarly to 2018, in 2019 the topic "internet of thing" was also the most widely used (11.76 percentage of publications include the term "internet of thing"). Next were the following topics: "personnel" (6.86 percentage of publications) and "manufacture" (6.7 percentage of publications).

In 2020, 9.53 percentage of publications included the topic “internet of thing”. The most frequent topics in 2020 also included: ”artificial intelligence” (8.32 percentage of publications), ”automation” (6.85 percentage of publications), ”employment” (6.71 percentage of publications) and ”digitalization” (6.58 percentage of publications).

In 2021, the top topics included: ”internet of thing” (11.67 percentage of publications), ”manufacture” (9.42 percentage of publications), ”artificial intelligence” (9.02 percentage of publications), ”digitalization” (8.62 percentage of publications) and ”automation” (6.9 percentage of publications).

In 2022, the most frequent topics included: ”worker” (10.24 percentage of publications), ”internet of thing” (8.5 percentage of publications), ”digitalization” (7.3 percentage of publications), ”artificial intelligence” (6.86 percentage of publications), ”digital transformation” (6.21 percentage of publications), ”manufacture” (5.88 percentage of publications), ”human resource management” (5.56 percentage of publications), ”collaborative robot” (5.45 percentage of publications) and ”personnel” (5.34 percentage of publications).

In 2023 (until July), the most popular topics involved: ”worker” (8.79 percentage of publications), ”digitalization” (7.58 percentage of publications), ”artificial intelligence” (7.27 percentage of publications), ”internet of thing” (6.67 percentage of publications), ”manufacture” and ”digital transformation” (5.15 percentage of publications, respectively). To sum up, the findings showed that the issue of collaborative robot, manufacture and internet of thing were the most important research areas. The significant part of the research also concerned engineering education and human resource management. However, some of the topics were becoming popular in the years following the analysis (e.g. “covid-19”, “higher education”).

5. Conclusions, Proposals, Recommendations

The purpose of this article is to investigate the purpose of this paper is to examine the vast literature on the labour market in the context of Industry 4.0, as well as to highlight main contemporary research streams on this issue. To address the objectives of this study, a bibliometric analysis is being conducted using Elsevier's Scopus database, which enables the gathering of a sample of 3,815 publications between 2011 and 2023. The study uncovers the main authors, the main publications, the authorship network, and the main institutions, keywords, as well as interconnections between them.

The analysis reveals a growing research interest in the intersection of labour markets and Industry 4.0, highlighting the relevance and timeliness of this research topic. The key research areas in the literature on the labour market and Industry 4.0 involve the following aspects of work: human-robot collaboration, employee qualification

and competence related to new technologies and processes of Industry, using human intellect and artificial intelligence in social entrepreneurship, workplace occupational health and safety, smart system that supports human workers in a rapidly changing production environment, the role of Smart Human Resources 4.0 in the process of talent development, and talent off-boarding process with the help of emerging technologies and change in the employee generation, methods supporting the design of human work integrated within cyber-physical-systems, the impact of Industry 4.0 technologies on manufacturing education and lifelong training of the skilled workforce, as well as the general consequences of employing progressive digital technologies in the workplace.

Thus, the key terms are related to many aspects of labour market, its participants, and processes. Consequently, the research areas are deeply aligned to the fields of economics, sociology, management, and engineering.

The main transformations occurred in the labour market due to the fourth industrial revolution relate to the following challenges for employees and employers in the digital era: ensuring the retention of jobs in a changing work environment; the need of training employees to shift their capacities to jobs with more complex processes; potential losses resulting from the integration of occupational safety and health into Industry 4.0; potential job losses caused by the new technologies; consequences for job activities and qualifications (e.g., "polarisation" of skills); necessity of learning new skills. The challenges also refer to the future research directions in terms of labour market and Industry 4.0.

The study indicates that the main technologies of Industry 4.0 in the context of labour market involve: Internet of Things, artificial intelligence, automation, augmented reality and digitalisation. Evidence illustrates that the fourth industrial revolution leads to the improvement of working environment conditions due to the possibility to implement Industry 4.0 technologies (e.g. virtual and augmented reality) in the training system in the workplace. Industry 4.0 technologies can also support human workers in a changing production environment by visualising relevant information or guiding the user through specific tasks.

Additionally, Industry 4.0 technologies can support occupational health, safety, and productivity for the Operator 4.0, and could also decrease potential occupational risks. Consequently, the fourth industrial revolution technologies can back up ergonomics in the workplace and increase the effectiveness of workers. However, the positive effects depend on the industry. Evidence illustrates also that it is crucial to involve employees in the changes planned in their company to obtain positive effects of Industry 4.0.

To conclude, the research contributes to the literature by addressing the substantial research gap on labour market in the context of the fourth industrial revolution. Moreover, the analysis might not only constitute an important contribution to the

literature, but could also serve as a basis for recommendations to the employers and employees in the digital era. In addition, the study includes the important recommendations and remarks from the methodological point of view.

As a part of further research, it is worth to conduct an analysis in terms of impact of the fourth industrial revolution on the labour market and its participants (e.g. how these changes influence employee motivation). Additionally, it might be useful to focus on specific, detailed issues of the labour market in the era of Industry 4.0 (e.g. ergonomics in workplace), using quantitative and qualitative methods.

However, it should be noted that similar to other bibliometric analyses, the study also exhibits certain limitations. One of the limitations is the fact that research fields evolve over time, and bibliometric data may not fully capture these dynamics, especially in emerging areas, such as processes of the fourth industrial revolution.

Secondly, the approach is based on overall effects of the fourth industrial revolution in the labour market, therefore the study may not offer insights into some nuances behind the publications and citations. Finally, the bibliometric analysis does not account for external factors (e.g., policy changes) that also influence research patterns.

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