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Manufacturing equipment retrofitting towards Industry 4.0 standards — a systematic overview of the literature

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ABSTRACT
The main purpose of this paper is a systematic literature review on retrofitting tools, equipment, and infrastructure in the industrial domain. The methods used for the research were a systematic literature review: publication analysis, selection of databases, and appropriate modification of queries in individual databases. Findings were presented using a map of keywords, clusters, and charts. The main result of the conducted research was the identification of the main trends in the retrofitting area. The trends developed within the review can support further research into the direction of retrofitting methods and the factors determining the choice of specific techniques and tools in the digitalisation of manufacturing enterprises.

KEY WORDS
Industry 4.0, retrofitting, Internet of Things, equipment modernisation and adaptation, smart manufacturing

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Introduction

Currently, rapid industrial production changes are evident. Guerreiro et al. (2018) pointed out that responding to them determines the survival of industrial companies. On the one hand, there is the development of systems, devices, and techniques called Industry 4.0. This trend drives the exponential growth in various technology uses related to smart manufacturing, data clouds, and big data processing. Data is provided by various types of sensors, many of which belong to the Internet of Things. Keshav Kolla et al. (2022) presented an example of a drill sensorisation

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that allowed data to be collected and then processed in a data cloud using machine learning techniques (Lins et al., 2018). Predictive maintenance and anomaly detection can be mentioned as solutions for the early detection of undesirable changes in process parameters or machine operation.

On the other hand, currently, entrepreneurs in the manufacturing sector are particularly exposed to such negative phenomena as sudden increases in raw material prices, changes in fuel prices, transport costs, and other occurrences that reduce production profitability. In addition, they have to meet increasingly stringent standards related to greenhouse gas emissions, comply with the principles of sustainability, and address labour shortages. Most important, however, is the continuous drive to increase the productivity and efficiency of industrial plants.

Niemeyer et al. (2020) proposed using techniques described in the first paragraph above, which can reduce the negative effects of the phenomena outlined below. This requires the adaptation of existing machinery fleets and their components, such as CNC machine tools, table drills, and others, to the requirements of smart manufacturing. It is often impossible to replace machines due to the cost of the whole operation. Therefore, the solution is to retrofit machines and equipment. This operation extends the existing capabilities of the machines by adding sensors that allow the monitoring of operating parameters and communication with systems used in industrial environments, such as SCADA, MES, or ERP.

Another important feature of retrofitting is its evolutionary adaptability, by making slight changes to a limited extent at a low cost and time. Such changes allow for gradual adaptation and rapid verification of the correctness and suitability of machine retrofitting and the creation of a required communication infrastructure. Furthermore, retrofitting supports the idea of sustainability by extending the life of machinery and equipment.

This article presents the results of a systematic literature review for retrofitting techniques and technologies (an analysis of the publications, bibliometric evaluation, and classification of the selected publication database). Different research stages were implemented according to Okoli's (2015) and Fisch and Block's (2018) recommendations. The novelty of the publication concerns the realisation of the review and description of the literature related to the field of retrofitting and its classification, as well as the extraction of the main trends presented in the literature.

This publication answers the following questions:

- What components are included in the retrofitting machinery and equipment concept?
- What are the main trends in the application and development of machinery and plant retrofitting?

The article consists of five parts. An introduction includes a description of the techniques and technologies connected to retrofitting. The second part presents the research methods. The third part is a description of the results obtained from the research. The fourth part discusses the results, and the fifth part is the article's summary.

1. What is retrofitting?

Currently, there is a noticeable increase in the implementation of concepts of Industry 4.0 and Smart Manufacturing in various industries (Camarena-Gil et al., 2020). This is linked to the need for the digitalisation of businesses to counteract the disruption of supply chains and optimise production. The technological development increases the availability of sensors, cloud computing, and data storage and processing methods using machine learning and artificial intelligence techniques.

Historically, the retrofitting of machine tools used in the manufacturing industry was obtained by adding numerical scales to conventional machines to allow the precise reading of process parameters for machining workpieces. This enabled partial automation of measurements and increased the quality of machining work. Kang and Suh (1997) referred to an algorithmisation of finding the best machinability for a five-axis machine tool. Modifications of this type allowed for numerical control. Younkin and Hesla (2008) presented the history of the development of currently used machines with CNC control. They have revolutionised industrial production and are now the standard applied in virtually all industries.

1.1. Sensors

Factory or manufacturing plant equipment components cannot always be remotely controlled, monitored, or communicated via an ICT system. Some mechanically and electrically operable components do not have sensors built in by the manufacturer, making it difficult to service them, predict failures and detect anomalies during their operation. Medina and Manera (2017) presented a case study where, by using wireless sensors as the Internet of

Things devices, they added new functionalities to an existing air-conditioning system. As a consequence of the modifications, the current version of the air-conditioning system allows for automatic control of the air conditioners considering outdoor conditions and detection of the people using them, thus saving energy. Kancharla et al. (2021) presented a retrofitting application using three current sensors and three voltage sensors for an induction motor, additionally visualising the measurements using an augmented reality application.

1.2. Clouds

Various data clouds are used to store and exchange data. They are characterised by their versatility and scalability depending on data processing needs. Among other things, the major cloud providers offer dedicated platforms for storing data, performing calculations, or running their applications. Based on Panda et al. (2020), a cloud was used as an integration layer for data received from sensors. In addition, by using the OPC UA protocol, it was possible to manage sensors and use the obtained data in machine learning algorithms. Integrations of sensor devices with the cloud platform were also performed using the MQTT protocol (Panda et al., 2019). Lima et al. (2019), on the other hand, presented an example of using the cloud to process energy usage data from the Internet of Things sensory devices and make it available as a digital twin model to third-party companies.

1.3. Algorithms for data processing

With sensors and data in the cloud, algorithms are required to generate new knowledge from raw data. Hesser and Markert (2019) used artificial neural networks to determine the tool wear of a CNC milling machine from accelerometer data. Another example of the use of neural networks is the assessment and monitoring of spindle conditions presented by Corne et al. (2017). One more example, presented by Pandiyan et al. (2018), is the application of support vector machines (SVMs) and genetic algorithms to analyse data from multiple sensors during the grinding process of an abrasive belt. A comparison of the use of random forests, neural networks and support vector regression (SVR) is presented for tool parameter evaluation (Wu et al., 2017). Measurements of forces and vibrations in three axes and generated sound intensity were used as data. Among data processing algorithms, methods for visualising data in virtual or augmented space can be distinguished. Al-Maeeni et al. (2020) presented the possibility of using HoloLens goggles as navigation support during the machine startup for the end user. Another example of using augmented reality is the retrofitting of an engine in a manufacturing system, described by Kancharla et al. (2021). The collected data is visualised using a dedicated web-based application. On the other hand, Mourtzis et al. (2020) presented a conceptual framework to support decision-making assisted by an online network and based on augmented reality for retrofitting and recycling machinery.

1.4. Industry 4.0

The works presented by Sanghavi et al. (2019) and Olsen and Tomlin (2020) outlined selected features of Industry 4.0, including the communication of machines interconnected through the Internet of Things devices, i.e., sensors, a cloud layer ensuring their integration and appropriate data exchange, machine learning, and artificial intelligence algorithms processing the collected data. An example of using an accelerometer to measure and monitor a CNC machine tool was given by Herwan et al. (2019). The authors used vibration measurements and the development and training of machine learning models to achieve a tool wear detection accuracy of 88 %. A proposal for a reference model and an architecture for implementing Industry 4.0 elements was presented by Pisching et al. (2018). The authors presented a model called RAMI 4.0 — a Reference Architecture Model for Industry 4.0. The subsequent layers of the model are Layer I — hardware, and products, Layer II — data integration and exchange layer, and Layer III — communication and information layer. Layer IV is the functional layer, and Layer V is the business layer. The hierarchical division allows flexible modelling of the Industry 4.0 elements and their simplified implementation. The most advanced example of the technologies included in Industry 4.0 is digital twins. Concepts for their use were presented by Gulewicz (2022).

2. Research methods

This publication uses the method of systematic literature review. In it, successive stages of bibliometric analysis were carried out. Successive stages of the review have been described in detail in several publications (Torres-Carrión et al., 2018, Xiao & Watson, 2019; Nightingale, 2009; Szpilko & Ejdys, 2022). As a first step, a selection of databases was made. Due to the search for publications in the field of engineering sciences, the topics of publications were limited to those related to manufacturing, industry, the use of sensors, and information technology. This allowed the selection of the three databases described below. The next stage consisted of selecting queries and limiting the cut-off date period to obtain the desired group of results.

The third step was the application of a restriction criterion allowing a reference to recent publications published in English and not withdrawn. The final stage of the study was a bibliometric analysis of the results obtained as a result of the previous steps. The next steps are shown in Fig. 1.

Based on the bibliometric analysis, the most productive countries, organisations, journals and authors were presented. An analysis of the most frequently used keywords was also performed.

The literature review was limited to the following bibliographic databases:

- Web of Science,
- Scopus,
- IEEE Explore.

The bibliometric analysis included publications containing the word "retrofitting" AND machines OR industry OR manufacturing OR device OR equipment OR factory in the title. The restriction to the title of the publication was introduced after a preliminary analysis of searches in all available fields. The next step was to set the appropriate inclusion criteria. Publications published between 2002 and 2022 in English were included in the analysis. Articles, reviews, conference proceedings, and books were submitted for analysis. The corresponding filter phrases for each are shown in Table 1 below.

Table 1 shows the results of the search in the databases. The first search in all possible fields yielded 6436 records in the Web of Science database, 6536 in the Scopus database, and 1316 in the IEEE Xplore database.

Adopting the inclusion criteria yielded 5763, 4729 and 917 records, respectively.

The analysis of the results showed that many of the publications were not related to the field under consideration, which is why the authors decided to limit the search to publications that contain the previ-

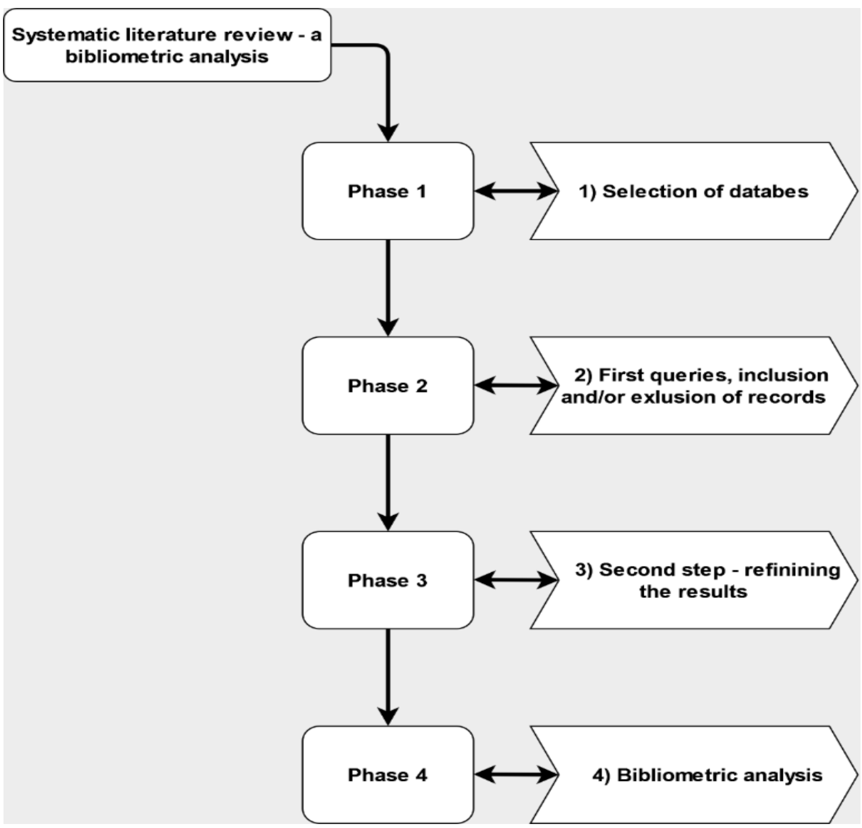

Fig. 1. Scheme of systematic literature review

Tab. 1. Summary of phrases used during the literature review

Phase	Web of Science	Scopus	IEEE Xplore
Research query 1	Analyse Results: retrofitting (All Fields) AND machines OR industry OR manufacturing OR device OR equipment OR factory (All Fields)	TITLE-ABS-KEY (retrofitting) AND TITLE-ABS-KEY (machines OR industry OR manufacturing OR device OR equipment OR factory)	"All Metadata":retrofitting AND ("All Metadata":machine OR "All Metadata":industry OR "All Metadata":manufacturing OR "All Metadata":device OR "All Metadata":equipment OR "All Metadata":factory)
Number of articles without inclusion criteria	6436	6536	1316
Number of articles with inclusion criteria	5763	4729	917
Research query 2	Analyse Results: retrofitting (Title) AND machines OR industry OR manufacturing OR device OR equipment OR factory (Title)	TITLE (retrofitting) AND TITLE (machines OR industry OR manufacturing OR device OR equipment OR factory)	„Document Title":retrofitting) AND („Document Title":machines OR „Document Title":industry OR „Document Title":manufacturing OR „Document Title":device OR „Document Title":equipment OR „Document Title":factory)
Number of articles without inclusion criteria	274	152	45
Number of articles with inclusion criteria	205	112	38

ously mentioned phrases in the title of the article. The results of the analysis are also presented in Table 1. Search queries only in the title of publications showed 274 records in the Web of Science database, 152 records in the Scopus database and 45 records in the IEEE Xplore database. After applying the inclusion criteria, the filtering results gave 205, 111 and 38 records, respectively.

Subsequently, one summary file was created containing 354 records after removing duplicates and incomplete records. The final file contains 266 records. In 2022, 12 publications were registered in the Scopus database, ten publications in the Web of Science database, and four publications in the IEEE Xplore database.

The article shows the changing interest in the topic over the years and identifies the main research areas, the most productive countries, journals, organisations, authors and the most frequently cited articles. The results of the analysis are presented in graphical form. Maps of keywords and their co-occurrences were drawn up. The co-occurrence of keywords was made based on a file downloaded from the Scopus database using VOSviewer software and the authors' thesaurus file.

3. Research results

Based on the results obtained from the Scopus database, keywords from publications were divided into clusters, shown in Table 2 and visualised in Fig. 2. As a result, the authors obtained five clusters containing 13 to four elements. The first and biggest cluster contains keywords connected mainly with the benefits of retrofitting.

The second includes different outcomes from upgrading machines that are pushing the industry towards smart manufacturing, data visualisation and, in general, Industry 4.0. The third contains different types of systems and subsystems used in the industry, e.g., computer control systems, embedded systems and computer-aided design techniques. The fourth cluster has keywords linked with commerce, industry in general and the state of the art solutions. The fifth cluster includes such general concepts as automation and robotics, connected with the industry's transformation towards Industry 4.0.

Fig. 3 shows the change in the number of publications related to retrofitting from 2002 to 2022. In blue, the graph shows the number of publications from the Web of Science database; the pattern of publications since 2015 is particularly evident. This correlates with the development of cloud technologies and the wide availability of techniques related to large data sets (big data). In other charts, the increase in the number of publications since 2015 is also evident. Fig. 4, on the other hand, shows the share of different types of publications in each database.

Fig. 4 shows a breakdown by the publication type, i.e., articles in scientific journals, conference materials and others. The vast majority of publica-

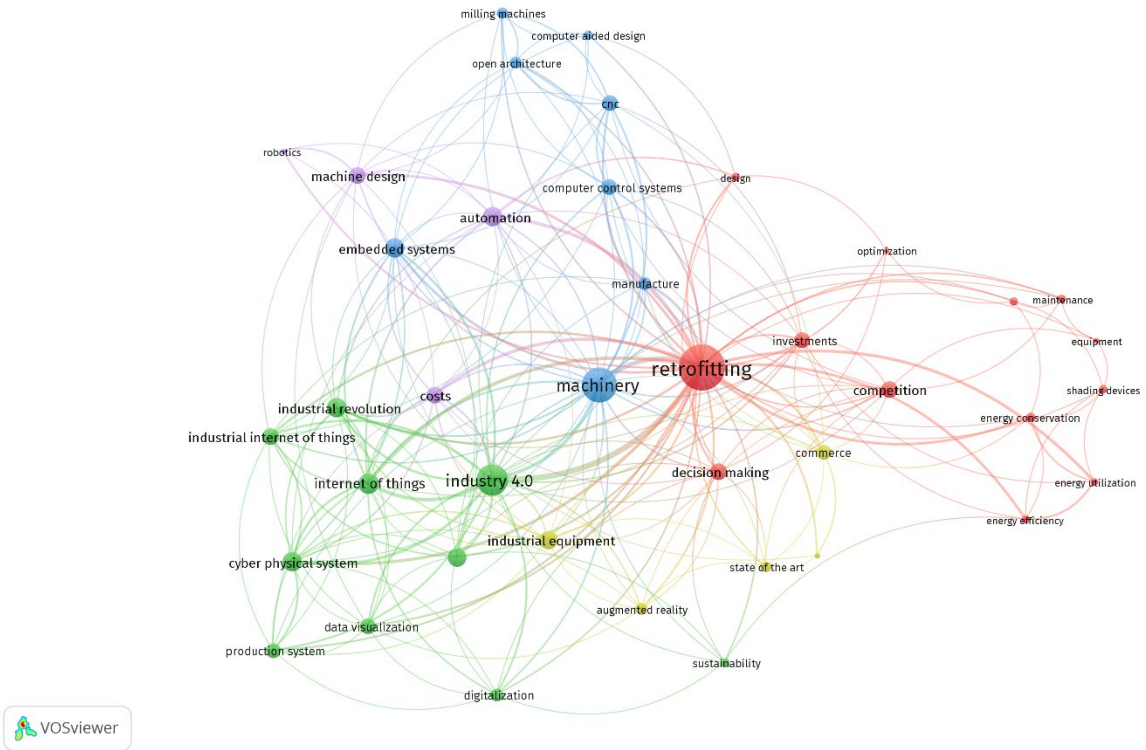

Fig. 2. Map of keyword associations and clusters

Tab. 2. Breakdown of keywords into clusters generated with VosViewer

Cluster 1 (13 items) Processes	Cluster 2 (10 items) Systems and concepts	Cluster 3 (8 items) Hardware and infrastructure
competition decision-making design energy conservation energy efficiency energy utilisation equipment investments retrofitting maintenance optimisation performance assessment shading devices	cyber-physical system data visualisation digitalisation industrial Internet of Things industrial revolution Industry 4.0 Internet of Things sustainability smart retrofitting production system	CNC computer-aided design computer-control systems embedded systems machinery manufacture milling machines open architecture

Cluster 4 (5 items) Industry	Cluster 5 (4 items) Automation and robotics
commerce augmented reality industrial equipment industry state-of-the-art	automation costs machine design robotics

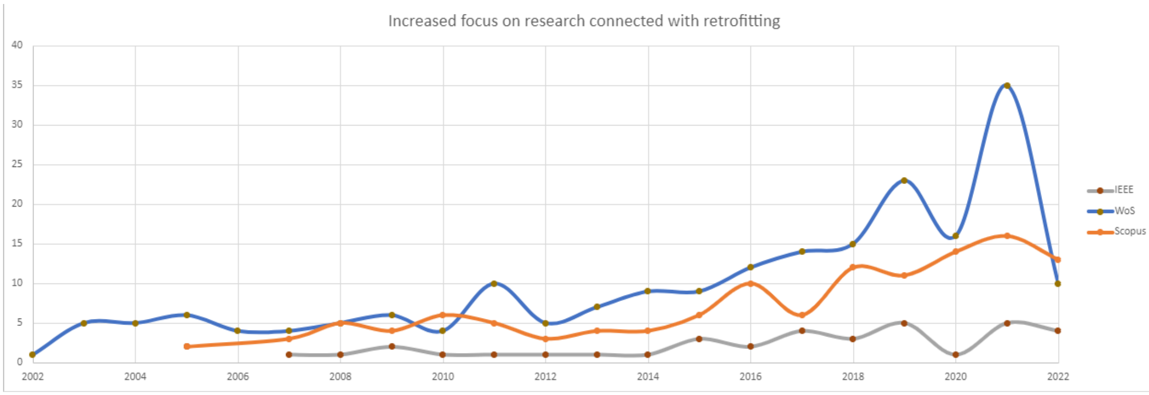

Fig. 3. Chart of the growing number of publications in the area of retrofitting

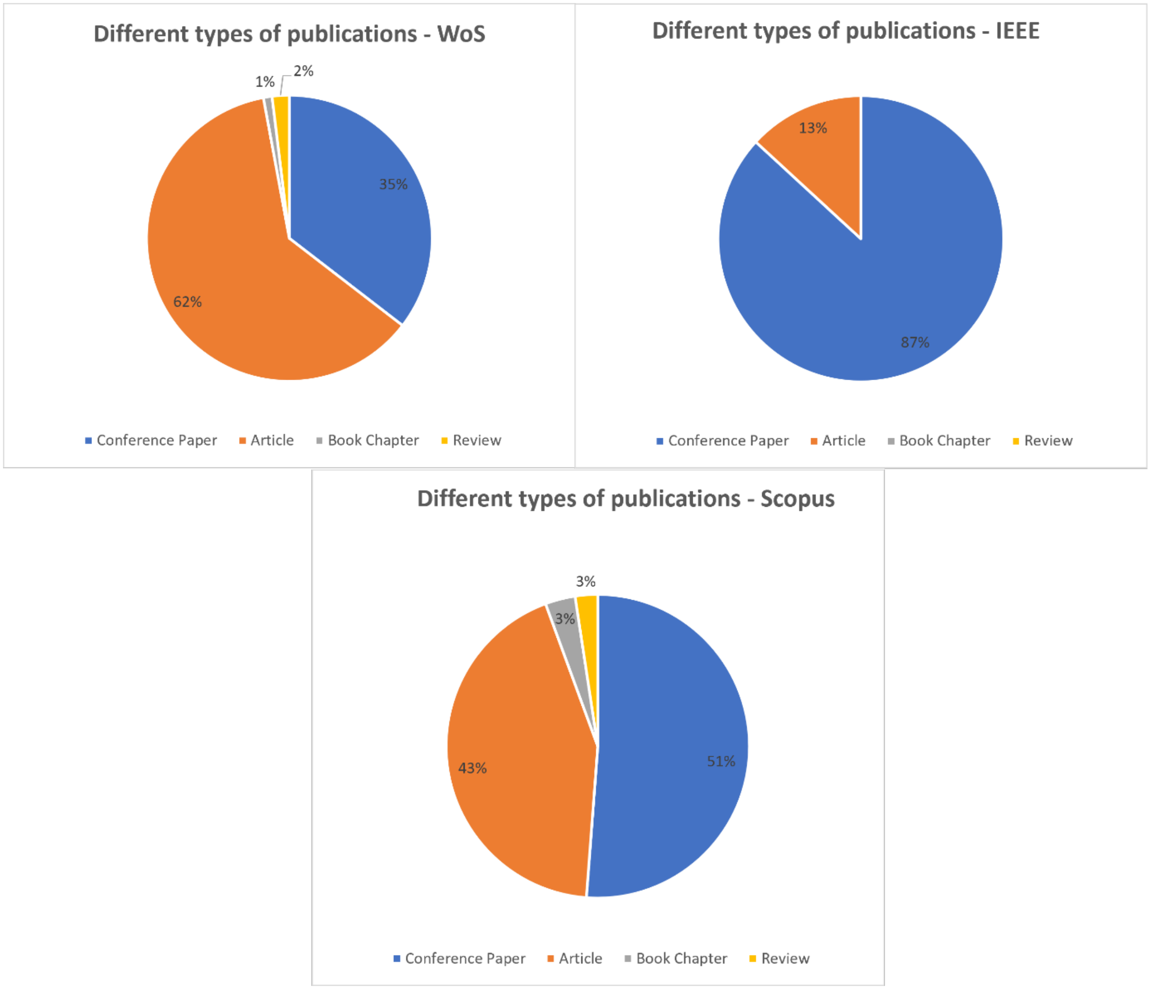

Fig. 4. Different types of publications for each database

tions were presented at scientific conferences, which indicates the topicality of the subject. The IEEE database shows that publications presented at scientific conferences account for as much as 87 % of all publications.

The smallest portion of publications in all databases are chapters in books.

Based on the analysis, a cloud of the most frequently occurring keywords was created. It can be noted that the resulting cloud contains phrases related to Industry 4.0, digitalisation, machines, and optimisation.

Table 3 summarises data on the most prolific countries, journals and organisations in terms of

Fig. 5. Most occurring key words

Tab. 3. Most productive countries, organisations and journals

No.	Item	Np	%OFT	Average citation count		
				WoS	Scopus	IEEE Xplore
	Most productive countries					
1	United States	36	13,5	15,1	10,9	0,67
2	Italy	29	10,9	9,0	8,7	4,0
3	United Kingdom	18	6,8	12,4	15,0	1,0
4	China	17	6,4	23,4	37,1	N/A
5	Germany	16	6,0	8,9	8,5	5,3
6	Iran	9	3,4	5,9	9,7	N/A
7	Taiwan	9	3,4	10,1	3,7	2,0
8	Brazil	8	3,0	14,0	33,8	9,6
9	South Korea	7	2,6	3,7	N/A	4,0
10	Spain	7	2,6	6,4	7,6	3,7
	Most productive organisations					
1	Fraunhofer gesellschaft	5	1,9	13,8	12,3	6,0
2	ETH Zurich	4	1,5	7,8	16,0	7,0
3	University of California system	4	1,5	2,8	N/A	N/A
4	University of Manchester	4	1,5	6,3	2	N/A
5	Aalto university	3	1,1	5,3	N/A	N/A
6	Consiglio nazionale delle ricerche CNR	3	1,1	8,0	0	N/A
7	Hanyang university	3	1,1	7,7	N/A	N/A
8	Industrial technology research institute Taiwan	3	1,1	1,7	N/A	2,0
9	Marche polytechnic university	3	1,1	5,3	N/A	N/A
10	University of California Berkeley	3	1,1	3,7	N/A	N/A
	Most productive journals					
1	IEEE Access	37	13,9	7,5	2,0	2,9
2	Engineering structures	9	3,4	10,8	N/A	N/A
3	Sustainability	8	3,0	9,3	7,8	N/A
4	Energies	5	1,9	3,6	6	N/A
5	Applied energy	4	1,5	20,3	N/A	N/A
6	Bulletin of earthquake engineering	4	1,5	6,5	N/A	N/A
7	Earthquake engineering structural dynamics	4	1,5	10,3	9,5	N/A
8	Advanced materials research	3	1,1	0,3	1,0	N/A
9	Energy and buildings	3	1,1	47,3	N/A	N/A
10	Journal of cleaner production	3	1,1	13,3	12,0	N/A

publishing. The United States (36 publications), Italy (29 publications) and the United Kingdom (18 publications) stand out with the highest numbers of publications over the analysed years. Given the most productive institutions, the largest number of publications came from Fraunhofer-Gesellschaft (five articles) and ETH Zurich and the University of California submitted four publications each. Regarding the most productive journals, the largest number of publications was published by IEEE Access (37 publications), Engineering structures (nine publications) and Sustainability (eight publications).

4. Discussion of the results

The systematic literature review presents the components of retrofitting in the domain of machinery and equipment. The review of publications confirmed the proposed division of the elements of retrofitting machines and devices into three components, i.e., sensory elements, clouds and the Internet of Things devices as communication elements, and artificial intelligence algorithms and machine learning techniques for making conclusions based on collected data.

Also, the authors identified five thematic fields of academic publications connected with retrofitting, shown in Fig. 2, i.e., (1) Processes, (2) Systems and Concepts, (3) Hardware and Infrastructure, (4) Industry, and (5) Automation and Robotics. The identified fields are also mutually connected, which shows their links on different levels. The thematic fields are presented in Fig. 6.

The first field — Processes — connects retrofitting as a process with terms and different ways of process optimisation. The main term — retrofitting — impacts different areas of upgrading the ability to monitor equipment and make processes more intelligent. This cluster consists of thirteen terms, mainly connected with creating additional value through such processes as decision-making, design, maintenance, optimisation and performance assessment. Retrofitting as a general proposal to upgrade a machine tool to Industry 4.0 standards is presented in the paper by Arjoni et al. (2017). The proposed methodology describes in detail the functional requirements, design parameters, data model and system architecture for retrofitting CNC machines, enabling engineers to create designs tailored to real industries. In contrast, a description of the framework process for transitioning an existing factory to Indus-

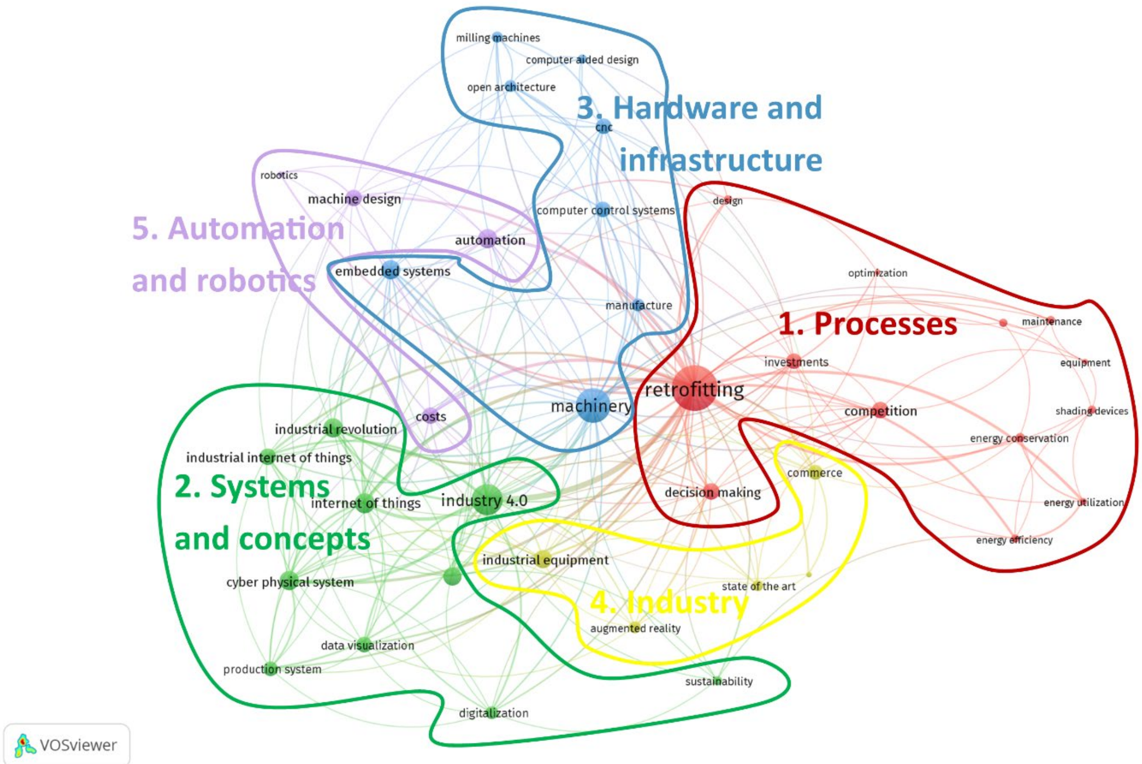

Fig. 6. Co-occurrence map with thematic fields connected with retrofitting

try 4.0 was presented by Carlo et al. (2021). This group also contains phrases connected with energy conservation, utilisation or increasing energy efficiency. This topic was considered in the paper by Lima et al. (2019).

The second field — Systems and Concepts — includes ten phrases connected with the (industrial) Internet of Things, digitalisation, production system and Industry 4.0 in general. This field describes methods for digitalisation and retrofitting of different components of production systems. Tantscher and Mayer (2022) proposed a procedure model for Digital Retrofitting, which is the result of analysing and grouping existing process models. This fills a gap in existing procedure models, which either address very general aspects or focus too little on digital retrofitting as holistic and multidimensional. A holistic approach to the problem of retrofitting allowed Ilari et al. (2021) to present a framework for assessing the sustainability of implementing a smart retrofitting process for old machines as an alternative to replacing them with new ones. Holistic development of the next stages of retrofitting machinery, equipment and processes was presented by Pisching et al. (2018).

The third field — Hardware and Infrastructure — contains eight phrases presenting the development of retrofitting methods, mainly technical solutions, connected with computer-aided design and control systems, embedded systems and their applications in manufacturing. Sridevi et al. (2015) presented a methodology for modernising CNC machines. Quatrano et al. (2017) described the development of a controller and open-loop control system to reuse an existing CNC machine to perform simple manufacturing operations. Panda et al. (2019) proposed a method for quality control by identifying the impact of process parameters and proposed architecture for retrofitting existing machines in the food industry area. Their solution involves implementing a hardware device capable of collecting a huge amount of process data and integrating it with a cloud-based platform for further analysis.

The fourth field — Industry — includes five phrases, such as commerce, augmented reality, industrial equipment, industry and state-of-the-art. The description concerns new component retrofitting technologies, such as cloud data, augmented or virtual reality, and their application to retrofitting machines and equipment. Xie et al. (2019) explored the potential of using Big Data Analytics (BDA) in smart cities. The paper examines how the interconnectedness of the Internet of Things, machine-to-machine communication, Big Data and Smart Cities can help anticipate and meet the needs of retrofitting projects. Another example of a publication describing the use of selected components of retrofitting is the description of a proposal for an architecture for retrofitting an older machine with external sensors presented by Keshav Kolla et al. (2022). Sensors are used to collect data and feed databases into the cloud for analysis and monitoring. In contrast, an example of using artificial neural networks to assess tool wear was described by Hesser and Markert (2019). Using augmented reality as a method for retrofitting a production machine was presented by Al-Maeeni et al. (2020).

The fifth field — Automation and Robotics — has four phrases: automation, costs, machine design and robotics. Arjoni et al. (2017) presented the retrofitting of automation and robotics components of manufacturing lines. Retrofitting can be beneficial in the context of upgrade costs by upgrading instead of exchanging devices. An example is retrofitting for data integration in the cloud, presented by Panda et al. (2020).

The fields described above intersect at phrases with the largest connection numbers. The main connection is at the centre of Fig. 6, between the terms retrofitting (1. Processes), machinery (3. Hardware and Infrastructure), Industry 4.0 (2. Systems and Concepts), industrial equipment (4. Industry) and automation (5. Automation and Robotics). The above connection can be the result of the interdisciplinary character of machine retrofitting used in the industry, especially in the transformation of current manufacturing elements to the standards of interconnected components of the Industry 4.0 concept. The literature review had no publications on the exact cost calculation of retrofitting and comparing it with the cost of purchasing a new machine that meets specific requirements. There were also no publications that would deal with the retrofitting of the entire production line and its adaptation to Industry 4.0. Also, there were no articles showing the quality of elements made on machines after retrofitting and new machines.

Conclusions

In this publication, a systematic literature review was carried out on retrofitting machinery and equipment in the manufacturing domain. The following steps were conducted: analysis of publications, selection of databases, appropriate modification of queries in individual databases, and presentation of results. There is an evident increase in interest in the retrofitti¬¬¬¬ng machinery and equipment, which is related to the desire for the implementation of techniques and technologies that enable the implementation of elements of Industry 4.0 in industrial plants.

The research allowed for identifying five research fields in analysed publications. The first, "processes", is connected with processes that are key components of retrofitting or could benefit from it. The second, "systems and concepts", describes different methods for digitalisation and retrofitting of various elements of production systems and manufacturing lines. The third, "hardware and infrastructure", includes mainly technical solutions connected with specific applications and implementations, e.g., embedded systems and their applications in the manufacturing or CNC-controlled machines. The fourth, "industry", contains different general component horizontal technologies of retrofitting, such as cloud data, augmented or virtual reality, among others, and their application to retrofitting machines and equipment. Lastly, the fifth, "automation and robotics", includes phrases connected with upgrading current automation and robotics to the standards of Industry 4.0. Additionally, the intersections and connections between fields were described using conclusions on possible reasons for connections between them, i.e., the interdisciplinary and multidimensional character of retrofitting. With the growth of artificial intelligence and general artificial intelligence, a higher impact of AI-related technologies on retrofitting is foreseen. Artificial intelligence will make the retrofitting process easier and faster. A few examples of the possible use are anomaly detection, sensor data classification or predictive maintenance. These technologies will optimise production, reduce downtime, increase predictability and prevent downtime. The new use of technology will enhance the quality of production processes, facilitate the retrofitting of machinery, and allow it to adapt smoothly to Industry 4.0.

A systematic literature review and the identified trends helped answer the two research questions posed at the beginning of the paper. Among the components of the techniques and technologies included in the retrofitting of machines and devices, a layer of sensory and communication elements can be distinguished, often integrated into the form of the Internet of Things devices. Another is a data cloud, enabling its storage and mediating its exchange. The last layer is artificial intelligence algorithms and machine learning techniques enabling automated inference based on processed data. The answer to the second question is presented in the fourth chapter, identifying the five thematic fields of publications in the area of machinery and equipment retrofitting.

The research limitations were related to using three bibliometric databases (Web of Science, Scopus and IEEE Explore) and choosing the scope of retrofitting connected with the manufacturing industry.

The next research stages will be to further divide and analyse retrofitting in terms of the adaptation of techniques and technologies and the progressive digitisation and digitalisation of manufacturing enterprises.

Literature

Al-Maeeni, S. S. H., Kuhnhen, C., Engel, B., & Schiller, M. (2020). Smart retrofitting of machine tools in the context of industry 4.0. *Procedia CIRP, 88*, 369-374. doi: 10.1016/j.procir.2020.05.064

Arjoni, D. H., Madani, F. S., Ikeda, G., Carvalho, G. de M., Cobianchi, L. B., Ferreira, L. F. L. R., & Villani, E. (2017). *Manufacture Equipment Retrofit to Allow Usage in the Industry 4.0*. 2017 2nd International Conference on Cybernetics, Robotics and Control (CRC), 155-161. doi: 10.1109/CRC.2017.46

Bergstrom, S. D., & Guenther, D. S. (2008). Retrofit of Power Centers Within an Airport. *IEEE Transactions on Industry Applications, 44*(6), 1918-1923. doi: 10.1109/TIA.2008.2006340

Burresi, G., Ermini, S., Bernabini, D., Lorusso, M., Gelli, F., Frustace, D., & Rizzo, A. (2020). *Smart Retrofitting by Design Thinking Applied to an Industry 4.0 Migration Process in a Steel Mill Plant.* 2020 9th Mediterranean Conference on Embedded Computing (MECO), 1-6. doi: 10.1109/MECO49872.2020.9134210

Camarena-Gil, E., Garrigues, C., & Puig, F. (2020). Innovating in the textile industry: An uncoordinated dance between firms and their territory? *Journal of Entrepreneurship, Management and Innovation*, *16*(3), 47-76. doi: 10.7341/20201632

Carlo, F. D., Mazzuto, G., Bevilacqua, M., Ciarapica, F. E., Ortenzi, M., Donato, L. D., Ferraro, A., & Pirozzi, M. (2021). A process plant retrofitting framework in Industry 4.0 perspective. *IFAC-PapersOnLine, 54*(1), 67-72. doi: 10.1016/j.ifacol.2021.08.007

Corne, R., Nath, C., El Mansori, M., & Kurfess, T. (2017). Study of spindle power data with neural network for predicting real-time tool wear/breakage during inconel drilling. *Journal of Manufacturing Systems, 43*, 287-295. doi: 10.1016/j.jmsy.2017.01.004

Fisch, C., & Block, J. (2018). Six tips for your (systematic) literature review in business and management research. *Management Review Quarterly, 68*(2), 103-106. doi: 10.1007/s11301-018-0142-x

Guerreiro, B. V., Lins, R. G., Sun, J., & Schmitt, R. (2018). Definition of Smart Retrofitting: First Steps for a Company to Deploy Aspects of Industry 4.0. In A. Hamrol, O. Ciszak, S. Legutko, & M. Jurczyk (Eds.), *Advances in Manufacturing* (pp. 161-170). Springer International Publishing. doi: 10.1007/978-3-319-68619-6_16Keshav Kolla, S. S. V., Lourenço, D. M., Kumar, A. A., & Plapper, P. (2022). Retrofitting of legacy machines in the context of Industrial Internet of Things (IIoT). *Procedia Computer Science, 200*, 62-70. doi: 10.1016/j.procs.2022.01.205

Gulewicz, M. (2022). Digital twin technology – Awareness, implementation problems and benefits. *Engineering Management in Production and Services, 14*(1), 63-77. doi: 10.2478/emj-2022-0006

Herwan, J., Kano, S., Ryabov, O., Sawada, H., Kasashima, N., & Misaka, T. (2019). Retrofitting old CNC turning with an accelerometer at a remote location towards Industry 4.0. *Manufacturing Letters, 21*, 56-59. doi: 10.1016/j.mfglet.2019.08.001

Hesser, D. F., & Markert, B. (2019). Tool wear monitoring of a retrofitted CNC milling machine using artificial neural networks. *Manufacturing Letters, 19*, 1-4. doi: 10.1016/j.mfglet.2018.11.001

Ilari, S., Carlo, F. D., Ciarapica, F. E., & Bevilacqua, M. (2021). Machine Tool Transition from Industry 3.0 to 4.0: A Comparison between Old Machine Retrofitting and the Purchase of New Machines from a Triple Bottom Line Perspective. *Sustainability, 13*(18), 10441. doi: 10.3390/su131810441

Kancharla, C. R., Bekaert, L., Lannoo, J., Vankeirsbilck, J., Vanoost, D., Boydens, J., & Hallez, H. (2021). *Augmented Reality Based Machine Monitoring for Legacy Machines: A retrofitting use case*. 2021 XXX International Scientific Conference Electronics (ET), 1-5. doi: 10.1109/ET52713.2021.9579936

Kang, J.-K., & Suh, S.-H. (1997). Machinability and set-up orientation for five-axis numerically controlled machining of free surfaces. *The International Journal of Advanced Manufacturing Technology, 13*(5), 311-325. doi: 10.1007/BF01178251

Keshav Kolla, S. S. V., Lourenço, D. M., Kumar, A. A., & Plapper, P. (2022). Retrofitting of legacy machines in the context of Industrial Internet of Things (IIoT). *Procedia Computer Science, 200*, 62-70. doi: 10.1016/j.procs.2022.01.205

Lima, F., Massote, A. A., & Maia, R. F. (2019). *IoT Energy Retrofit and the Connection of Legacy Machines Inside the Industry 4.0 Concept*. IECON 2019 – 45th Annual Conference of the IEEE Industrial Electronics Society, 5499-5504. doi: 10.1109/IECON.2019.8927799

Lins, T., Augusto Rabelo Oliveira, R., H. A. Correia, L., & Sa Silva, J. (2018*). Industry 4.0 Retrofitting*. 2018 VIII Brazilian Symposium on Computing Systems Engineering (SBESC), 8-15. doi: 10.1109/SBESC.2018.00011

Medina, B. E., & Manera, L. T. (2017). *Retrofit of air conditioning systems through an Wireless Sensor and Actuator Network: An IoT-based application for smart buildings.* 2017 IEEE 14th International Conference on Networking, Sensing and Control (ICNSC), 49-53. doi: 10.1109/ICNSC.2017.8000066

Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2020). Recycling and retrofitting for industrial equipment based on augmented reality. *Procedia CIRP, 90*, 606-610. doi: 10.1016/j.procir.2020.02.134

Niemeyer, C. L., Gehrke, I., Müller, K., Küsters, D., & Gries, T. (2020). Getting Small Medium Enterprises started on Industry 4.0 using retrofitting solutions. *Procedia Manufacturing, 45*, 208-214. doi: 10.1016/j.promfg.2020.04.096

Nightingale, A. (2009). A guide to systematic literature reviews. *Surgery (Oxford), 27*(9), 381-384. doi: 10.1016/j.mpsur.2009.07.005

Okoli, C. (2015). A Guide to Conducting a Standalone Systematic Literature Review. *Communications of the Association for Information Systems, 37*. doi: 10.17705/1CAIS.03743

Olsen, T. L., & Tomlin, B. (2020). Industry 4.0: Opportunities and Challenges for Operations Management. *Manufacturing & Service Operations Management, 22*(1), 113-122. doi: 10.1287/msom.2019.0796

Panda, S. K., Blome, A., Wisniewski, L., & Meyer, A. (2019). *IoT Retrofitting Approach for the Food Industry*. 2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), 1639-1642. doi: 10.1109/ETFA.2019.8869093

Panda, S. K., Wisniewski, L., Ehrlich, M., Majumder, M., & Jasperneite, J. (2020). *Plug & Play Retrofitting Approach for Data Integration to the Cloud*. 2020 16th IEEE International Conference on Factory Communication Systems (WFCS), 1-8. doi: 10.1109/WFCS47810.2020.9114523

Pandiyan, V., Caesarendra, W., Tjahjowidodo, T., & Tan, H. H. (2018). In-process tool condition monitoring in compliant abrasive belt grinding process using support vector machine and genetic algorithm. *Journal of Manufacturing Processes, 31*, 199-213. doi: 10.1016/j.jmapro.2017.11.014

Pisching, M. A., Pessoa, M. A. O., Junqueira, F., dos Santos Filho, D. J., & Miyagi, P. E. (2018). An architecture based on RAMI 4.0 to discover equipment to process operations required by products. *Computers & Industrial Engineering, 125*, 574-591. doi: 10.1016/j.cie.2017.12.029

Quatrano, A., De, S., Rivera, Z. B., & Guida, D. (2017). Development and implementation of a control system for a retrofitted CNC machine by using Arduino. *FME Transaction, 45*(4), 565-571. doi: 10.5937/fmet1704565Q

Sanghavi, D., Parikh, S., & Raj, S. A. (2019). *Industry 4.0: Tools and Implementation*. doi: 10.24425/MPER.2019.129593

Sridevi, S., Dhanasekar, J., & Manikandan, G. (2015). *A methodology of retrofitting for CNC vertical milling machine*. 2015 International Conference on Robotics, Automation, Control and Embedded Systems (RACE), 1-4. doi: 10.1109/RACE.2015.7097257

Stock, T., & Seliger, G. (2016). Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP, 40*, 536-541. doi: 10.1016/j.procir.2016.01.129

Szpilko, D., & Ejdys, J. (2022). European Green Deal – research directions. a systematic literature review. *Ekonomia i Środowisko - Economics and Environment, 81*(2), 8-38. doi: 10.34659/eis.2022.81.2.455

Tantscher, D., & Mayer, B. (2022). Digital Retrofitting of legacy machines: A holistic procedure model for industrial companies. *CIRP Journal of Manufacturing Science and Technology, 36*, 35-44. doi: 10.1016/j.cirpj.2021.10.011

Torres-Carrión, P. V., González-González, C. S., Aciar, S., & Rodríguez-Morales, G. (2018). *Methodology for systematic literature review applied to engineering and education*. 2018 IEEE Global Engineering Education Conference (EDUCON), 1364-1373. doi: 10.1109/EDUCON.2018.8363388

Wu, D., Jennings, C., Terpenny, J., Gao, R. X., & Kumara, S. (2017). A Comparative Study on Machine Learning Algorithms for Smart Manufacturing: Tool Wear Prediction Using Random Forests. *Journal of Manufacturing Science and Engineering, 139*(7). doi: 10.1115/1.4036350

Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research, 39*(1), 93-112. doi: 10.1177/0739456X17723971

Younkin, G., & Hesla, E. (2008). Origin of Numerical Control [History]. *IEEE Industry Applications Magazine, 14*(5), 10-12. doi: 10.1109/MIAS.2008.927525

Zambetti, M., Khan, M. A., Pinto, R., & Wuest, T. (2020). Enabling servitization by retrofitting legacy equipment for Industry 4.0 applications: Benefits and barriers for OEMs. *Procedia Manufacturing, 48*, 1047-1053. doi: 10.1016/j.promfg.2020.05.144

Xie, H., Shi, W., Choudhary, H., Fu, H., & Guo, X. (2019). *Big Data Analysis for Retrofit Projects in Smart Cities*. 2019 3rd International Conference on Smart Grid and Smart Cities (ICSGSC), 1-5. doi: 10.1109/ICSGSC.2019.00-28