Management and Industrial Engineering

Carolina Machado
J. Paulo Davim *Editors*

Smart Engineering Management

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Carolina Machado · J. Paulo Davim
Editors

Smart Engineering Management

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Editors
Carolina Machado
Department of Management
School of Economics and Management
University of Minho
Braga, Portugal

J. Paulo Davim
Department of Mechanical Engineering
University of Aveiro
Aveiro, Portugal

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Preface

The demands of the markets and the increasingly high levels of competitiveness, so visible today, are not compatible with the existence of mechanistic and bureaucratic organizations, based on reactive and adaptive management models. On the contrary, today's organizations need to be proactive, leading to the emergence of new and growing needs among their key stakeholders (customers—internal and external-, suppliers and shareholders, among others) that promote high levels of flexibility, quality, creativity and responsiveness. To this end, in addition to the material and financial resources, always necessary to the organizations' survival, anticipating the market requires, from these last ones, the promotion and implementation of dynamic and visionary policies and strategies only possible thanks to the existence of a diversified range of skills and talents based in a human force properly prepared, trained and informed at the different knowledge levels, namely: knowing how to do, knowing how to be and knowing how to know. Together and in an articulated manner, they contribute to the definition of new and challenging management philosophies, leading to increasingly higher levels of competitiveness. Bearing in mind these concerns and current challenges faced by different organizations, the present book proposal, entitled *Smart Engineering Management* can be understood as an important tool at the disposal of the different "curious" in the areas of smart/intelligent business and management, providing support for an adequate understanding of the problems and challenges faced by current organizations, as well as an effective knowledge of the different management policies and practices that lead to increased levels of productivity and profitability. For a more effective knowledge dissemination in the field of business, management and engineering sciences, this book counts with the contribution of a diverse range of experts with the most recent and diversified knowledge in the different areas of business/management and engineering. Encouraged to identify the theoretical and practical implications of the different areas of business/management and engineering, in order to provide a more effective understanding and implementation of these issues in different types of organizations.

Being encouraged the authors to identify, within the scope of smart engineering management, the theoretical and practical implications in the different areas of management and engineering, in order to provide a more effective understanding

and implementation of these issues in different types of organizations, the present book, organized in seven chapters, begins by addressing "Smart Technologies as a Tool for Increasing the Competitiveness of the Company", followed by "Taking Customer-Centricity to New Heights: Exploring the Intersection of AI, Hyper-Personalization, and Customer-Centricity in Organizations". The next chapter highlights the "Contribution of Industry 4.0 Technologies in Adopting Metrology 4.0 in Manufacturing Industries", then talking about "Agile Human Resource Management: A Theoretical Contribution to a (R)evolutionary Approach for Managing People at Work". "Mapping and Conceptualising Eco-Innovation Practices on Environmental Performance" is also a target of analysis, then focusing on Managing and Engaging a Multigenerational Workforce in Portugal. The book ends with an approach to Talent Management and Smart Organizations: A Strategic Symphony.

Smart Engineering Management can be used by a variety of potential stakeholders, namely academics/researchers, managers, engineers, practitioners and other professionals who develop their professional activity in different areas of business and management. A very special target audience consists of undergraduate/graduate students, for whom this book will provide a fundamental support by providing a detailed and highly up-to-date view of the main subjects—in its theoretical and practical components—underlying the management of dynamic, competitive and socially responsible organizations, as are today' organizations.

The Editors acknowledge their gratitude to Springer for this opportunity and for their professional support. Finally, we would like to thank all chapter authors for their interest and availability to work on this project.

Braga, Portugal Carolina Machado
Aveiro, Portugal J. Paulo Davim

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Editors and Contributors

About the Editors

Carolina Machado received her Ph.D. degree in Management Sciences (Organizational and Policies Management area/Human Resources Management) from the University of Minho in 1999, Master's degree in Management (Strategic Human Resource Management) from Technical University of Lisbon in 1994, and Degree in Business Administration from University of Minho in 1989. Teaching in Human Resources Management subjects since 1989 at University of Minho, she is since 2004 Associate Professor (with Habilitation since 2022), with experience and research interest areas in the field of Human Resource Management, International Human Resource Management, Human Resource Management in SMEs, Training and Development, Emotional Intelligence, Management Change, Knowledge Management and Management/HRM in the Digital Age/Business Analytics, Sustainability and Higher Education for Sustainability. She is Head of the Human Resources Management Work Group at the School of Economics and Management at University of Minho, Coordinator of Advanced Training Courses at the Interdisciplinary Centre of Social Sciences, Member of the Interdisciplinary Centre of Social Sciences (CICS.NOVA.UMinho), University of Minho, as well as Chief Editor of the International Journal of Applied Management Sciences and Engineering (IJAMSE), Guest Editor of journals, books Editor and book Series Editor, as well as reviewer in different international prestigious journals. In addition, she has also published both as editor/co-editor and as author/co-author of several books, book chapters and articles in journals and conferences. e-mail: carolina@eeg.uminho.pt

J. Paulo Davim is a Full Professor at the University of Aveiro, Portugal. He is also distinguished as honorary professor in several universities/colleges/institutes in China, India and Spain. He received his Ph.D. degree in Mechanical Engineering in 1997, M.Sc. degree in Mechanical Engineering (materials and manufacturing processes) in 1991, Mechanical Engineering degree (5 years) in 1986, from the

University of Porto (FEUP), the Aggregate title (Full Habilitation) from the University of Coimbra in 2005 and the D.Sc. (Higher Doctorate) from London Metropolitan University in 2013. He is a Senior Chartered Engineer by the Portuguese Institution of Engineers with an MBA and Specialist titles in Engineering and Industrial Management as well as in Metrology. He is also Eur Ing by FEANI-Brussels and a Fellow (FIET) of IET-London. He has more than 35 years of teaching and research experience in Manufacturing, Materials, Mechanical and Industrial Engineering, with special emphasis in Machining & Tribology. He has also an interest in Management, Engineering Education and Higher Education for Sustainability. He has guided large numbers of postdoc, Ph.D. and master's students as well as has coordinated and participated in several financed research projects. He has received several scientific awards and honors. He has worked as an evaluator of projects for ERC-European Research Council and other international research agencies as well as an examiner of Ph.D. theses for many universities in different countries. He is the Editor in Chief of several international journals, Guest Editor of journals, books Editor, book Series Editor and Scientific Advisory for many international journals and conferences. He has been listed in World's Top 2% Scientists by Stanford University study. e-mail: pdavim@ua.pt

Contributors

Teresa Treviño Benavides Department of Management, Universidad de Monterrey, San Pedro Garza García, Mexico

Alice Gomes Coelho School of Economics and Management, University of Minho, Braga, Portugal

Eduardo González-Treviño Department of Digital and Transformation, Deacero, San Pedro Garza García, Mexico

Lucia Knapčíková Faculty of Manufacturing Technologies, Department of Industrial Engineering and Informatics, The Technical University of Košice, Prešov, Slovak Republic

Regina Leite School of Economics and Management, University of Minho, Braga, Portugal;
Interdisciplinary Centre of Social Sciences (CICS.NOVA.UMinho), University of Minho, Braga, Portugal

João Lima School of Economics and Management, University of Minho, Braga, Portugal

Carolina Feliciana Machado School of Economics and Management, University of Minho, Braga, Portugal;
Interdisciplinary Centre of Social Sciences (CICS.NOVA.UMinho), University of Minho, Braga, Portugal

Victoria Mahabi Department of Mechanical and Industrial Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania

Flor Morton Department of Management, Universidad de Monterrey, San Pedro Garza García, Mexico

Jailos Mrisho Nzumile Department of Legal and Industrial Metrology, College of Business Education (CBE), Dar es Salaam, Tanzania;
Department of Mechanical and Industrial Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania

Abraham G. Pamba Department of Mechanical and Industrial Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania

Lurdes Pedro Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Setúbal, Portugal

Célia Quintas Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Setúbal, Portugal

João Leite Ribeiro School of Economics and Management, University of Minho, Braga, Portugal;
Interdisciplinary Centre of Social Sciences (CICS.NOVA.UMinho), University of Minho, Braga, Portugal

José Rebelo Santos Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Setúbal, Portugal

Ismail W. R. Taifa Department of Mechanical and Industrial Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania

Smart Technologies as a Tool for Increasing the Competitiveness of the Company

Lucia Knapčíková

Abstract In recent years, the manufacturing industry has developed rapidly with the advent of advanced technologies such as smart manufacturing, Industry 4.0 and the Internet of Things (IoT). These technologies offer opportunities to increase efficiency, improve quality control and expand decision-making capabilities. Therefore, many manufacturing companies are looking for ways to implement smart technologies in their operations. However, the implementation of smart technologies is challenging. It requires a complex strategy that takes into account the unique needs and capabilities of each individual company. Technologies that can sense changes in their conditions and take measures to improve their functionality in new conditions offer huge benefits in terms of performance, efficiency, operating costs and resilience. These technologies can be very useful for businesses because they can quickly respond to changes in the environment and improve their performance.

Keywords Smart · Technology · Manufacturing · Company

1 Introduction

The fourth industrial revolution consists of new technologies that are applied to the production process. These technologies include robotics, artificial intelligence, the Internet of Things, autonomous vehicles, 3D printing, quantum computers and nanotechnology (Tran & Hu, 2019). Currently, these technologies are mainly used in the space, aviation, automotive and electronics industries, but they can be expanded to other production areas. Industry 4.0 means digitisation and networking of internal company processes and represents an application of IoT to production and the creation of the Industrial Internet of Things. Like the Internet of Things, we are talking about smart mobiles, smart homes, smart cities and smart healthcare (Tran & Hu, 2019; Mesaros et al., 2020). Industrial Internet is the basis of the concept of

L. Knapčíková (✉)
Faculty of Manufacturing Technologies, Department of Industrial Engineering and Informatics, The Technical University of Košice, Prešov, Slovak Republic
e-mail: lucia.knapcikova@tuke.sk

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the so-called smart businesses and smart industry. The core of intelligent industry is the Internet of Things connected with modern control systems. Smart enterprises can achieve high labour productivity, reduce production, logistics and transportation costs, manage costs and shorten the time to market new products (Tran & Hu, 2019; Mesaros et al., 2020). In addition, they can produce individualised and specialised products at a cost comparable to mass production (Perisa et al., 2019).

In smart companies, a pleasant working environment is created, and production is more ecological because they use natural resources and energy more efficiently. Despite this, intelligent industry still has reserves in the integration of production and information-communication technologies. Industry 4.0 marks a significant shift towards the digitisation of industry and the automation of production, which is based on the cybernetic connection of production information systems in industrial enterprises (Mesaros et al., 2020). This concept includes digitising all three attributes of the manufacturing process, including software, equipment and people. Industry 4.0 is used to apply a network of digital interconnection of objects and exchange distributed data between them in industrial enterprises—this industry of the future, which is based on cyber-netic-physical systems and networks (Perisa et al., 2019) (Fig. 1).

Industry 4.0 is currently being discussed as the future of productivity and growth in the manufacturing industry (Mesaros et al., 2020; Perisa et al., 2019). Industry 4.0 will change every step of the production process, from design to technical support of products and production systems. The relationship and cooperation between parts, machines and people will enable production systems to achieve up to 30% faster speed

Fig. 1 Technologies for Industry 4.0 (Tran & Hu, 2019; Author own processing, 2023)

and 25% more efficiency, which will increase the ability of mass personalisation to a level we have not known before. Orders and customer requests will be sent directly to the production lines via the Internet, allowing the processing of orders at the cost of producing large series. Assuming that Industry 4.0 will continue to develop, it is expected that within ten years, manufacturing enterprises will fundamentally change (Perisa et al., 2019; Straka et al., 2018). This process will result in the creation of the so-called Smart factories, where intelligent devices will take over all manual and service activities and, with the right management systems, will organise the efficient running of production by themselves (Straka et al., 2018).

1.1 The Smart Methodology

Currently, SMART is a phenomenon that is already firmly established among people. It represents humanity's next development stage, which can combine all the knowledge we have acquired in different fields (Straka et al., 2018). Automation of processes in enterprises is already common, meaning the first step towards SMART enterprises, in which classical production systems use information and communication systems (ICT). In the near future, every device will be connected to the Internet. The Internet of Things (IoT) is already one of the key technologies of our time (Nagyova et al., 2021). Research in digital enterprise, reconfigurable systems, intelligent systems, automation and simulation was one of the prerequisites for the emergence of Industry 4.0 (Tran & Hu, 2019; Nagyova et al., 2021). When determining key performance indicators (KPIs), it is useful to use the auxiliary method SMART, which enables the correct formulation of the goal. However, it can also be applied when defining performance indicators. According to this method, the following conditions should be met for the key performance indicator to be SMART (Fig. 2):

S–specific, that is, the indicator is precisely defined so that it is clear what it is specifically tracking. It must be understandable to all interested parties;
M–measurable, which means quantifiable, having assigned units (e.g. SI units, derived, etc.). The indicator must be able to be assessed throughout the process, not only at the beginning or only at the end;
A–achievable, that is, conditions exist or will be created so that the KPI can be applied. They include, e.g. available technical means, technology, knowledge…;
R–realistic, which means a practically applicable indicator. It must be based on an objective assessment of performance and the possibilities for achieving it. It is linked to "A";
T–limited in time, traceable in time, scheduled. The indicator must reflect its tendency, i.e. whether its performance corresponds to the established assumptions. "T" is the frequency with which we evaluate the given hand (Nagyova et al., 2021; Meining et al., 2019).

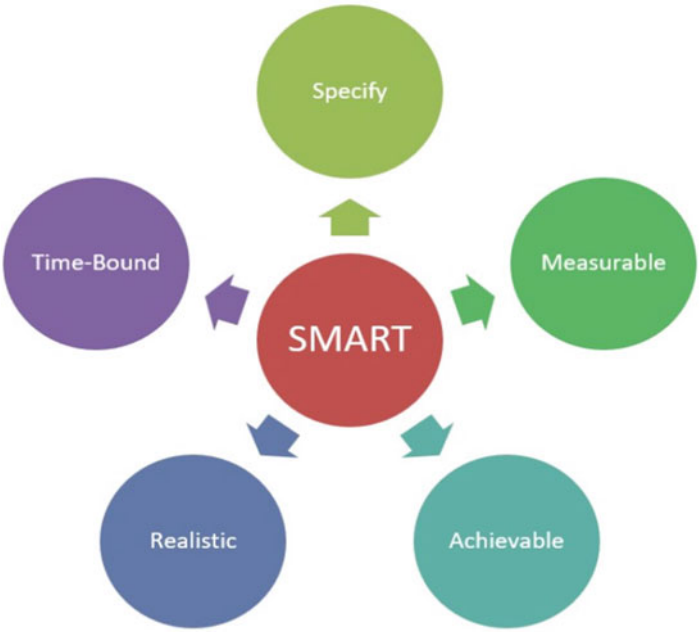


Fig. 2 The smart method (Author own processing, 2023)

1.2 Basic Principles of Industry 4.0

The Industry 4.0 concept is based on five basic principles (Meining et al., 2019):

1. Interoperability

The success of the Industry 4.0 concept depends on the close cooperation between people and cyber-genetic-physical systems (CPS), which are connected through the Internet of Things and Services. These elements are the key tools of this concept.

2. Virtualisation

CPS (cyber-physical systems) enable monitoring of physical processes and their connection with the virtual model of the enterprise using sensors. The virtual model creates a copy of the physical world, which enables the simulation of various processes and optimisation in a digital enterprise in a 3D environment, for example, maintenance.

3. Decentralisation

As market demands for products increase, so does management complexity, which can be tiring for a central control system. However, embedded computers allow individual devices to make decisions and control themselves, thus achieving highly decentralised system management.

4. Capacities in real-time

The organisation must collect and analyse data in real-time to successfully manage its activities. This way, the organisation can immediately react to problems, such as equipment breakdowns or moving production to another facility.

5. Service orientation

CPS and people are accessible through the IoT and can offer their services to others, including internal or external parties. These services can be accessed through web services. This cooperation enables the creation of conditions for group companies located in several locations to use the production capacities of other plants and exchange services.

Smart production is a broad concept of production to optimise production and product transactions with full use of advanced information and production technologies (Perisa et al., 2019). It is considered a new production model based on intelligent science and technology, which greatly improves the design, production, management and integration of the entire life cycle of a typical product (Tran & Hu, 2019; Meining et al., 2019). Intelligent enterprise and intelligent manufacturing are part of the technological transformation known as Industry 4.0 or the Fourth Industrial Revolution. Each of the first three industrial revolutions was born from an innovative new technology that completely changed work and the production of goods: the steam engine, assembly line and performance. Today, the fourth revolution is driven by digital transformation and intelligent automation (Meining et al., 2019). The key feature of intelligence is the deep transformation and digitisation of the organisation's business processes for the necessary automation of production and algorithmisation of industrial enterprises (Karakai, 2023). Production technologies are based on creating physical and virtual infrastructure for communication and interaction of various elements of production processes. Artificial intelligence in manufacturing involves using technology to automate complex tasks and uncover previously unknown patterns in manufacturing processes or workflows (Tran & Hu, 2019; Meining et al., 2019). Artificial intelligence systems can improve things like loading cycle times, a narrow production profile, high production waste levels, or low output per hour of work. Organisations can find ways to improve that impact on the bottom line by recording, measuring and analysing specific external data (Karakai, 2023).

1.2.1 Internet of Things (IoT)

Industry 4.0 focuses on developing intelligent enterprises that use cyber-physical systems (CPS) and the Internet of Things (IoT) to achieve a high degree of adaptability, resource performance and time and energy efficiency (Meining et al., 2019). The communication network that connects objects in production includes materials, machines and equipment, robots, conveyors, sensors and internal and external logistics. These objects are part of cyber-physical systems (CPS) and can communicate with each other through the Internet of Things (IoT). Industry 4.0 is based on

the Internet of Things (IoT) principle and intelligent manufacturing, which enables machines to connect and create intelligent networks throughout the value chain (Karakai, 2023). These networks can autonomously communicate and manage themselves without operators' intervention, significantly simplifying processes (Nagyova et al., 2021).

The Internet of Things (IoT) brings new value through connectivity (Meining et al., 2019).

- People–Sensors connected to the production process will enable a detailed view of individual operations and the entire supply chain in a wider range of production, not just high-value processes as is the case today. Using the Internet of Things in manufacturing will help improve business by connecting people with the information they need, available on the right devices where they are needed. This approach will also enable the involvement of suppliers, maintenance partners and distribution chains in the company's processes. To do this, new software will be needed to allow managers to access data such as equipment efficiency, line efficiency, data visualisation tools and alerts anywhere in the world via PC, tablet or smartphone. These improvements will be available at a much lower cost than previous software systems.
- Processes–In the first stages of implementing the Internet of Things (IoT), manufacturers will focus on solving specific problems, such as supply issues. Manufacturers can deploy these systems that customers will use and start using managed solutions. As part of the spread of IoT, manufacturers will strive to enable a faster flow of information, which will guarantee faster decision-making and greater flexibility in the market, as devices will be integrated into operational and business software processes. Machine-to-machine (M2M) communication will enable a new level of automation. For example, GM uses sensory data to decide if a car is too wet to spray paint. If the system detects unfavourable conditions, the vehicle will be diverted to another part of the production process, minimising the vehicle's paint and maximising the business's operational efficiency. These changes brought the company savings in the millions of euros.
- Data–Mobility and the Internet of Things (IoT) will change the types of devices that connect to a company's systems, and these new devices will produce new kinds of data. The IoT will connect physical devices such as sensors, actuators, video cameras and RFID readers to the internet and each other. Processing a large amount of data and analysing it will be a key element, and cloud solutions will collect and analyse data from the IoT. These solutions turn data into context to help people and machines make relevant and correct decisions.

1.2.2 Maintenance 4.0

Industrial development and new technologies have also always required adaptation in maintenance (Karakai, 2023). Currently, maintenance can be modernised and made more efficient using SMART technologies. Maintenance 4.0 includes an advanced system of distribution components that provides information about their condition

and reliability (Karakai, 2023; Rosová et al., 2020). This information is important for properly managing and administrating assets, so it is crucial to have access to it for the right strategy in this direction. Prysmian has developed a new system for monitoring distribution components that can bring real savings in maintenance costs. One of the solutions it offers is Par-SMART Aden, based on smart tags with RFID technology that provides detailed information about products (Rosová et al., 2020). These labels can track distribution components and keep an accurate history of tracked parts. In this way, monitoring new and older components will be possible. The Maintenance Show in Munich brings together many exhibitors from the field, but Apple was also present, showing off various smartphones and tablets configured for device maintenance purposes. Apple promotes its devices, emphasising sustainability and Maintenance 4.0 as key elements of successful and intelligent maintenance (Meining et al., 2019; Rosová et al., 2020). Bilfinger presented new mobile information systems and cloud solutions for data management at the maintenance fair. These presentations show that the Internet of Things (IoT) has already reached the maintenance field. Visitors could use their mobile phones to take and share photos in real-time with colleagues and business partners.

Six trends are discussed for the maintenance revolution (Karakai, 2023; Rosová et al., 2020).

- E-maintenance

A shared platform such as Proteus or Telma enables verification of maintenance and machine data through a standardised interface.

- RFID technology

Mobile devices provide great potential for material, staff and support management. By using them, operating equipment, materials and containers can be identified, and data from the central storage is available to employees on the intranet.

- Augmented and virtual reality

This technology combines virtual and real-world elements and visualises data and work procedures. With its help, it is possible to connect data with real objects and workers in the field with experts in the headquarters. Google Glasses can be an example of such technology.

- Visualisation

Obtaining data is only the first step, but the source of information must also be properly processed and provided to workers on production lines and management stations with direct access to data. These visualisation systems are used to set weak points and quickly assess the condition of machines.

- Assistance systems

Personnel in fast and more efficient interpretation and diagnosis of data. These tools are designed to speed up and simplify the diagnostic process and make it easier for

available technical-technical personnel to identify problems and find solutions to their problems.

- Knowledge sharing and networking

Networking should eliminate access to the knowledge and expertise of company employees to ensure that valuable information is not lost and is available to other team members or even machinery and equipment.

2 Smart Factory

A smart or intelligent enterprise is a computerised physical system that uses advanced technologies such as artificial intelligence (AI) and machine learning to analyse data, control automated processes and learn (Fig. 3) (Nagyova et al., 2021). Many traditional businesses use automated machines such as barcode scanners, cameras and digitised production equipment in various parts of their operations. However, these devices are not interconnected (Karakai, 2023). A traditional enterprise's people, assets and data management systems operate separately and must be manually coordinated and integrated continuously (Song et al., 2012).

A smart enterprise integrates machines, people and Big Data into a single, digitally connected ecosystem (Song et al., 2012). An intelligent enterprise not only analyses data but learns from experience. Interprets and extracts information from data sets to forecast trends and events and to recommend and implement intelligent manufacturing workflows and automated processes (Hugos & Hulitzky, 2010). An intelligent

Fig. 3 Smart factory and its role in manufacturing (Nagyova et al., 2021; Author own processing, 2023)

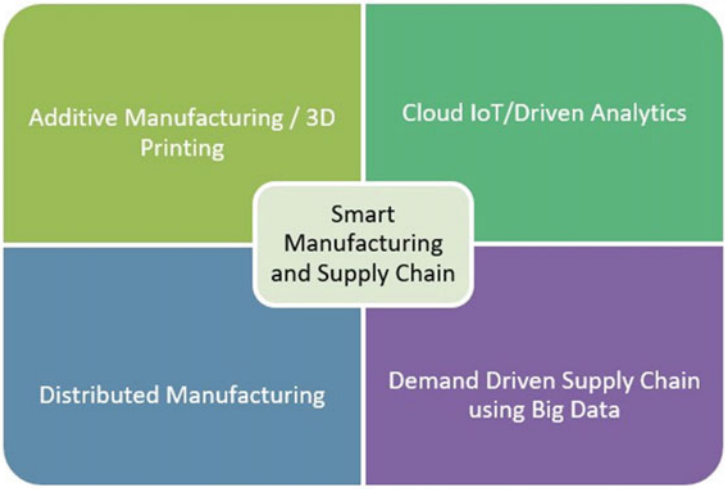


Fig. 4 The supply chain of the Smart Factory (Author own processing, 2023)

enterprise goes through a constant procedural improvement of self-correctness and self-realisation—it can learn itself (and a person) to be more resilient, productive and safer (Fig. 4).

The basic structure of an intelligent enterprise can be summarised in three steps (Hugos & Hulitzky, 2010).

1. Collection of data

Artificial intelligence and modern database technologies enable the processing and acquisition of diverse sets of useful data within the entire business and supply chain. Through sensors and gateways, data can be collected into the system, collecting data sets related to performance, market trends, logistics or any other potentially relevant source.

2. Data analysis

Machine learning and intelligent enterprise systems use advanced analytics and modern data management solutions to make sense of all the disparate data collected. Market and operational data can be collected to identify opportunities and risks. Workflow efficiency can be continuously investigated to optimise performance and to optimise automatic correction as warranted.

3. Intelligent automation

After data collection and analysis are done, workflows are created and instructions are sent to devices within the system. Intelligent workflows and processes are constantly monitored and optimised.

2.1 Artificial Intelligence

Intelligence is a characteristic acquired by certain living organisms during evolution (Hugos & Hulitzky, 2010; Prandi et al., 2017). Intelligence is also associated with artificial research, which deals with creating machines that can solve complex problems and learn by acquiring new knowledge. This mental ability of higher organisms makes it possible to solve complex tasks creatively, to remember the method of solving and to use the acquired knowledge in searching for and creating new solutions (learning). The ability to abstract thinking, logical reasoning, consciousness and self-reflection are closely related to intelligence (Fiebig et al., 2015). In computer systems development, the concept of artificial intelligence deals with creating systems capable of performing tasks that normally require human intelligence, such as voice recognition, image processing, decision-making, learning and the like. In the 1950s, the research and development of artificial intelligence began (Matt et al., 2020). In 1950, the English mathematician Alan Turing proposed the criterion, which was supposed to verify whether a computer with artificial intelligence can communicate with a person so that the person does not know that he is communicating with the computer. This led to the first artificial intelligence tests (Fiebig et al., 2015). If a computer can convince a human that it is communicating with another human instead of a machine, it will meet the criterion of the Turing test. This suggests that a computer has the same intelligence as a human (Fiebig et al., 2015).

2.1.1 Intelligence Manufacturing System (IMS)

An Intelligent Manufacturing System (IMS) comprises various manufacturing elements that work together to enable rapid and efficient adaptation to changes in the surrounding environment (Fiebig et al., 2015; Matt et al., 2020). These elements may include robots, sensors, software systems, chips and other devices. IMS is based on modern technologies such as IoT, big data, artificial intelligence and robotics to achieve higher automation and efficiency. IMS also has a flexible architecture that allows easy adaptation to customer or market needs changes. In this context, the term "production on demand" is used, which means that production is adapted to customers' requirements (Rosová et al., 2020; Matt et al., 2020). This, in turn, leads to smaller volumes of stock and lower storage costs. IMS also enables the collection and analysis of large amounts of data from manufacturing processes, which enables better quality control, prediction of future problems and improvement of manufacturing processes (Nagyova et al., 2021; Hugos & Hulitzky, 2010; Worden et al., 2003). This data analysis can also be used to optimise production processes, thereby reducing costs and increasing efficiency. Overall, IMS is based on the integration of technologies and processes to create an intelligent manufacturing system that is adaptable, flexible and efficient. IMS enables the creation of intelligent production, which can respond to changes in the surrounding environment and compete effectively in the market. Integration with manufacturing intelligent technologies is

required to create a unified intelligent manufacturing system (Worden et al., 2003). These technologies include software, hardware, information, communication and cyber-physical solutions that connect all production system elements. Creating a unified intelligent manufacturing system is challenging for integrating different information types. Therefore, intelligent technologies are expected, which are a group of approaches to production based on artificial intelligence technologies (Fiebig et al., 2015).

3 Current Possibilities of Using Smart Technologies in Manufacturing Processes

The use of intelligent technologies in production allows us to create intelligent production complexes and systems, interactively design the image of an industrial organisation and create the future architecture of an intelligent production organisation (Chmielarz, 2019). A single structural model allows all production participants to represent the performed functions and problem areas at different levels of the control activity of the organisation (socio-economic level, production and technological level, information and telecommunication level, etc.). Using smart sensors, adaptive decision-making models, advanced materials, smart devices and data analytics can improve the entire product life cycle (Worden et al., 2003). This leads to increased efficiency of production quality of products and services. The company's ability to face the dynamics and fluctuations of the global market can be increased and thus increase its competitiveness in the production field (Fiebig et al., 2015; Chmielarz, 2019).

Smart production technologies represent a promising direction of development and use of artificial intelligence to solve economic problems and improve integrated production processes. Operating systems that use integrated AI technologies have the speed, power and flexibility to collect and analyse heterogeneous data sets and provide real-time insights and responsive recommendations (Karakai, 2023; Fiebig et al., 2015). Automated processes and systems within the intelligent factory are constantly optimised and informed by artificial intelligence acquired by some living organisms in evolutionary development. Machine learning is part of artificial intelligence, which focuses on developing methods and algorithms that allow a programme to automatically learn and adapt to different input data without explicit programming. This means that the programme can develop its solutions based on the information it has learned in the learning process (Karakai, 2023; Chmielarz, 2019).

Machine learning algorithms include elements of mathematical statistics and statistical analysis methods that work with precise data. Data analysis is also used to identify trends and patterns in data. The output of machine learning is an estimate or prediction that is based on calculations and accurate data. Algo-rhythms can perform three basic tasks: classification, regression or clustering. These algorithms

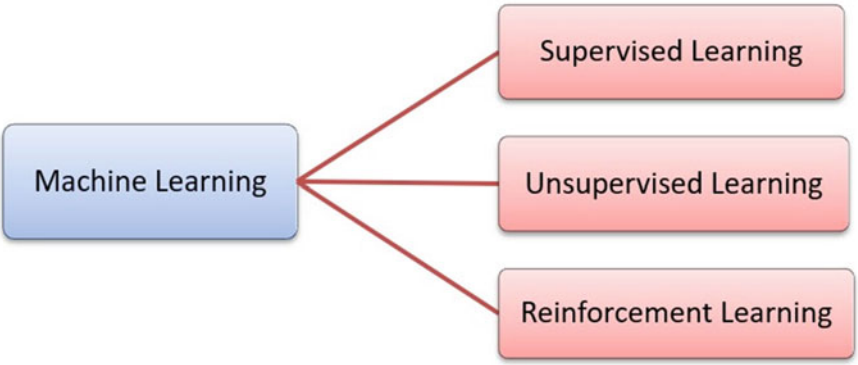


Fig. 5 Main categories of machine Llearning [Author own processing]

are divided into three categories according to the learning method (Fig. 5) (Hozdic, 2015).

– Learning with a teacher, or supervised learning,
– Learning without a teacher or unsupervised learning
– Reinforcement learning.

One of the most valuable benefits that machine learning brings is its capacity for advanced predictive maintenance (Song et al., 2012; Hozdic, 2015). By monitoring and analysing production processes, it is possible to send alerts before the occurrence of a system failure. Depending on the situation, automated maintenance can be performed, or human intervention can be recommended. An exact, virtual replica of a machine or system becomes its digital twin. It enables maximum innovation and creativity with minimal operational risk (Hozdic, 2015). A digital twin can be pushed to its limit, reconfigured in multiple virtual ways, or tested for compatibility within an existing system—all without creating risk or wasting resources in the physical world (Fig. 6).

The mission of a digital twin is to be able to quickly and accurately say (Rojko, 2017).

- What caused some undesirable event in the production or logistics process, for example, downtime, at the same time, recommend how to solve it and prevent such situations.

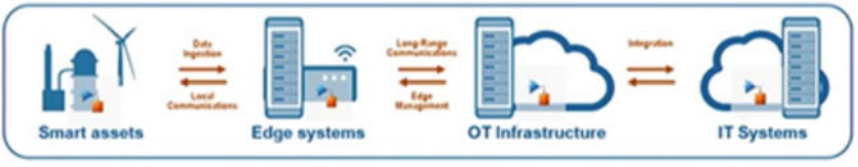


Fig. 6 Digital Twin and real manufacturing process (Hozdic, 2015), (Author own processing, 2023)

- How to organise and optimise the sequence of orders so that production, given the current plan, produces as many products as possible.
- When to replace the tool because it has reached the limit of its useful life.

3.1 Intelligent Manufacturing

Research and development in production is focussed on increasing the efficiency of enterprises, improving processes for obtaining and processing new materials, equipment and systems and optimizing procedures in producing industrial goods (Rojko, 2017). The research and development of production must correspond to the latest scientific discoveries so that manufacturers can quickly apply innovations in processes and products (Worden et al., 2003; Rojko, 2017).

Thanks to ever-increasing computing activities and new information and communication technology options that are becoming more affordable, we will soon reach technological advances that will allow us to build intelligent manufacturing processes and systems with the following capabilities (Rojko, 2017).

- Timely recognise and solve the threats of the irregular operational status of the production system,
- Continuously monitor, diagnose and optimise all important functional parameters of the process and its performance,
- Carry out self-calibration when a deviation is recorded, predict preventive maintenance and warn of the need for service,
- Identify the standard quality of work of the production system and take steps to improve it,
- Automatically capture, sort and record process knowledge catalogue,
- Enable the production of products in small quantities,
- Recognise changes and recommend appropriate responses of workers to maintain system stability,
- Work in an energy-saving mode and environmentally friendly,
- Automatically increase worker safety and enable intuitive interactions.

4 Work Methodology

The main production process (Fig. 7) is carried out in the main workshop (marked in green), while the auxiliary production process is carried out in the auxiliary workshop (marked in yellow). The site also contains a material warehouse (marked in red in the picture), where materials and finished products awaiting shipment are registered.

The main production process is producing additional equipment and lifting equipment for forklifts. The associated production process was recently opened and mainly serves to ensure its own needs in producing hydraulic cylinders and distributors so that they are self-sufficient and independent of the addition of semi-finished products

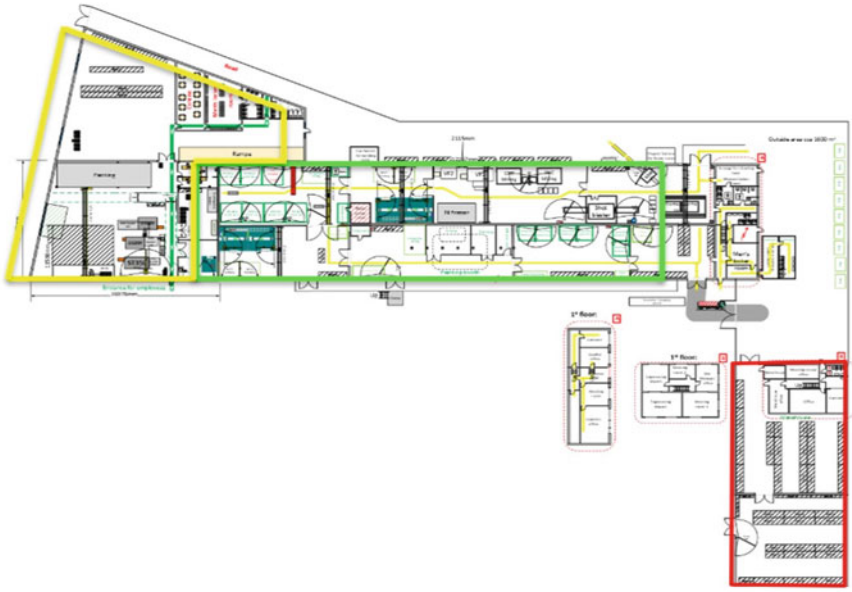


Fig. 7 Layout of the manufacturing process (Karakai, 2023; Author own processing, 2023)

from other suppliers. The main process (Fig. 8) is almost divided into departments. Since it is a small batch or rather piece production, a transport batch of 15–20 pieces per day can pass through the individual departments.

Legend

1. division and sandblasting department (dd = 15–20 pcs),
2. CNC machining division (dd = 15–20 pcs),
3. welding division (dd = 15–20 pcs),
4. painting division (dd = 15–20 pcs),
5. assembly division (dd = 15–20 pcs),
6. division of final control and packaging (dd = 15–20 pcs).

Fig. 8 Main manufacturing process (Karakai, 2023; Author own processing, 2023)

Based on the data provided, it was found that the manufacturing company has an established corporate information system, Microsoft Dynamics 365 Business Central. The company purchased 20 licences for the management and management of the company. The Microsoft Dynamics 365 Business Central information system is used for financial management, customer relationship management, project management, supply chain management, reporting and analytics, production, service order management, warehouse management and travel orders (Wang et al., 2021; Espindola et al., 2013). As it is a batch production operation, most operations require human intervention. Production begins with the customer's demand, who can choose from a wide range of products in the catalogue. The specifications can be changed and adapted to the requirements in the Engineering Directive 2006/42/EC [Directive of the European Parliament and the Council 2006/42/EC of 17 May 2006 on machinery and the amendment of the directive 95/16/EC]. The order is registered in the company information system, and production begins. Based on the requirements, which can be adapted, the technical documentation and the 3D model (as a demonstration for the customer) are adjusted with the possible calculation (Karakai, 2023; Espindola et al., 2013).

The welding department performs robotic welding of frames and manual welding, especially where the robot cannot capture or does not have a set program. Welded parts are checked before output. Then, a coat of paint is applied to all components and frames in the painting department. Next comes the assembly department, where the entire frame for the forklift is assembled by hand, and the entire process is done manually. Finally, individual orders undergo a final inspection and are packed and shipped to the warehouse or directly to the customer (Karakai, 2023). All production takes place on working days (so-called "tak-ty") from Monday to Friday, with the fact that the week starts on Friday from Clock no. 5 when the shipment of finished products takes place.

5 Proposal for the Implementation of Smart Technologies in a Manufacturing Enterprise

The Real-Time Production Monitoring system combines individual elements of smart technologies into one idea—"real-time" (Karakai, 2023; Espindola et al., 2013). This means that production will be clear and visualised. Workers will have a better overview of what is happening in production and will be prepared for a certain amount of work in progress.

Advantages

- Increased clarity and visualisation of output in real-time enables faster identification of problems and adaptation of production.

- Workers have a better overview of what is happening in production and are prepared for production in progress, which can lead to higher efficiency and productivity.
- Managers can monitor and prepare individual workplaces, which enables optimisation of the material flow based on data from IS.
- Production management and planning improvement can reduce costs and increase profits.

Disadvantages

- Higher costs for system implementation and operation and special hardware and software needs.
- The need for a fast and reliable Internet connection for the system's proper functioning.
- Some workers may have problems adapting to the new system and mastering its use.

The system will benefit managers and workers by possibly monitoring and preparing individual workplaces (Osborne & Mavers, 2019). This could optimise the material flow based on data from IS, as managers will be able to design new production capacities and production plans, and workers will be ready to optimise and prepare workplaces for the required product pieces. The above-mentioned company information system is currently used only by the company's leadership and management because the workers do not have access to it and work based on the provided production plans, which do not always correspond to the actual production state. The implementation of the Real-Time Production Monitoring (RTPM) (Karakai, 2023; Osborne & Mavers, 2019) system was mainly considered in the assembly and welding departments (Fig. 9).

It would be difficult for other departments (parting, CNC, painting) because tracking each component throughout production would be necessary instead of just tracking one complete product. If it was mentioned above, it is possible to apply the smart technology of the RTPM system in two departments. The management of the production company is considering a suitable implementation in the assembly department with the possibility of later application to other workplaces as well. It is possible to apply the smart technologies of the RTPM system in several departments.

Fig. 9 Suitable workplaces for implementing the RTPM (Karakai, 2023; Author own processing, 2023)

The management of the production company considers the suitability of implementation in the assembly department and, subsequently, the possibility of application to other workplaces. Real-time production monitoring is a process that monitors and collects data on production operations and processes as they happen (Adcock & Gunn, 2015). It includes recording information from various sensors and systems within the production process, which is then processed and displayed in clear graphic presentations and reports (Chatzopoulos et al., 2017). This process aims to provide businesses with up-to-date information on the performance and efficiency of their production so that they can respond quickly to problems, improve overall efficiency and reduce costs. Various parameters such as production speed, schedule, production capacities, production costs and product quality are monitored in real-time (Koller et al., 2020).

This data is then analysed to identify problems and opportunities to improve production performance (Chatzopoulos et al., 2017; Huang et al., 2012). Real-time production monitoring is usually implemented using production management software, which enables tracking and collecting real-time data and visualisation through clear graphic presentations and reports. This procedure is important for businesses trying to improve their performance and increase production efficiency (Mourtzis et al., 2015). The assembly department mainly deals with the complete assembly of all order components (Fig. 10). It consists of 6 assembly workplaces, shelves for orders and storage of components.

The tasks of the assembly department include:

- Installation and assembly of equipment and components,
- Testing and verifying the proper functioning of equipment,
- Maintenance and repairs of equipment,

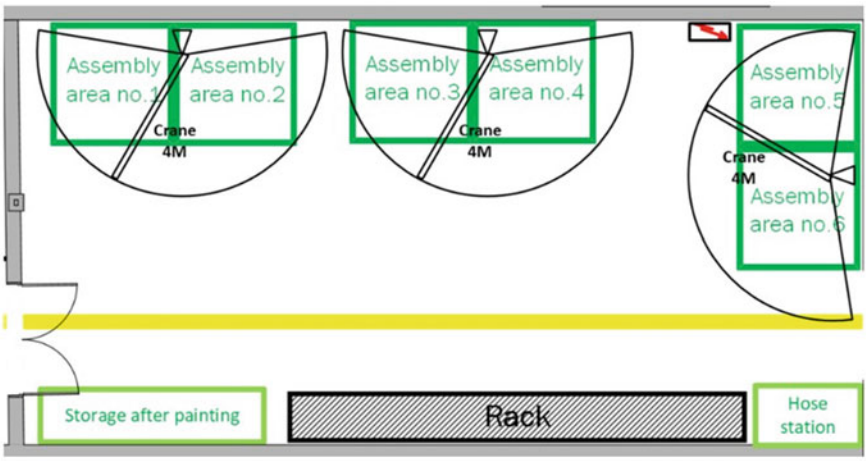


Fig. 10 Current state of the workplace (Karakai, 2023; Author own processing, 2023)

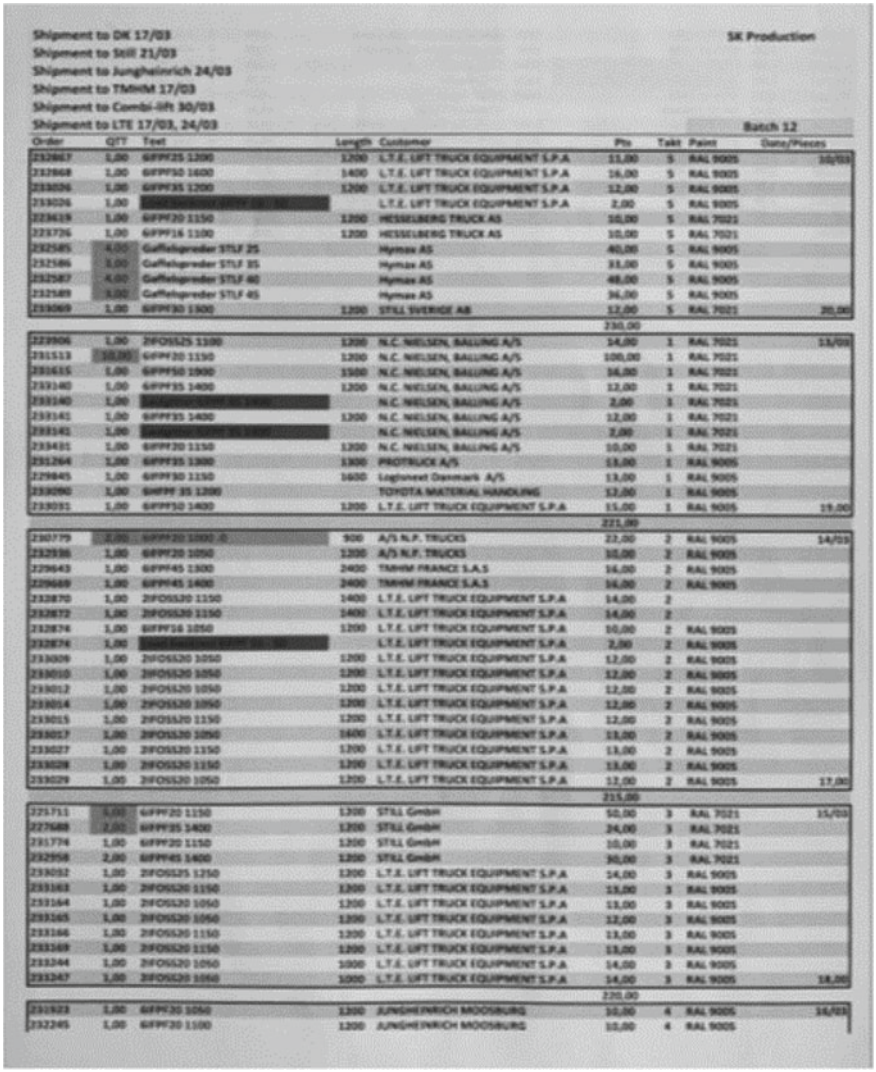
- Ensuring that all installations and assemblies are by valid standards and regulations,
- Cooperation with other departments.

Operators work based on technical documentation, which they receive in printed form. The main data are order number, customer, device configuration, description and barcode. During the day, workers scan their orders, and the number of orders in the system is updated. This updated data is then compared with the weekly production plan (Fig. 11).

The productivity and quality table is located where there is also a planning table, which contains the technical documentation of each order divided according to production cycles and their phases. There is also a screen that currently serves to display selected parameters from the quality department.

6 Results and Discussion

To improve the productivity and quality of the assembly in the company, a proposal was developed to use existing means and ideas in the assembly department. The proposed solution includes the implementation of the RTPM system (Karakai, 2023; Han & Zhao, 2015) clarity and visualisation of data in the form of electronic tables and graphs, which will be connected to the in-house information system and will mainly serve to familiarise workers with weekly plans, the current state of production and progress in the department. The data will be broadcast on the screen, directly drawn from the information system and constantly updated. The screen above the planning table in the assembly department could be used to display the results. The production department deals with the processing of orders, weekly plans and analysis of the current state of the entire production. They also develop technical documentation according to which workers must manage their work. In the department itself, the communication process of the worker with the terminal installed there is important. The worker scans the bar code before starting and at the end of the assembly and sends data to the system about the status of his order. Based on this, the information system updates the production status. In our case, this process would be shown in the assembly hall on a screen, and the workers would have a complete overview of the production status. The goal is to introduce the RTPM system and the requirement for visualisation, clarity and graphical interpretation of production data (Lamberti et al., 2014). Plan the budget and determine the employees who will deal with it. Next, system configuration is required. This means supplementing the existing corporate information system concerning the needs of the assembly department and defining the necessary parameters for data collection and monitoring, such as production speed, schedule, production capacities, production costs and product quality. As the company's management needs more knowledge to configure the Microsoft Dynamics 365 system, it will be necessary to involve external administrators responsible for maintenance, expansion of options and configuration of the method according to


Shipment to DK 17/03
Shipment to Still 21/03
Shipment to Jungheinrich 24/03
Shipment to TMHM 17/03
Shipment to Combi-lift 30/03
Shipment to LTE 17/03, 24/03
SK Production
Batch 12
Order | QTY | Text | Length | Customer | Pts | Takt | Paint | Date/Pieces
232867 1,00 6FPF35 1200 1200 L.T.E. LIFT TRUCK EQUIPMENT S.P.A 11,00 5 RAL 9005 10/03
232868 1,00 6FPF50 1600 1400 L.T.E. LIFT TRUCK EQUIPMENT S.P.A 16,00 5 RAL 9005
233026 1,00 6FPF35 1200 1200 L.T.E. LIFT TRUCK EQUIPMENT S.P.A 12,00 5 RAL 9005
233026 1,00 L.T.E. LIFT TRUCK EQUIPMENT S.P.A 2,00 5 RAL 9005
223619 1,00 6FPF20 1150 1200 HESSELBERG TRUCK AS 10,00 5 RAL 7021
223726 1,00 6FPF16 1100 1200 HESSELBERG TRUCK AS 10,00 5 RAL 7021
232585 4,00 Gaffelgreder STLF 25 Hymax AS 40,00 5 RAL 9005
232586 3,00 Gaffelgreder STLF 35 Hymax AS 33,00 5 RAL 9005
232587 4,00 Gaffelgreder STLF 60 Hymax AS 48,00 5 RAL 9005
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231513 10,00 6FPF20 1150 1200 N.C. NIELSEN, BALLING A/S 100,00 1 RAL 7021
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233141 1,00 N.C. NIELSEN, BALLING A/S 2,00 1 RAL 7021
233431 1,00 6FPF20 1150 1200 N.C. NIELSEN, BALLING A/S 10,00 1 RAL 7021
231264 1,00 6FPF35 1300 1300 PROTRUCK A/S 13,00 1 RAL 9005
229845 1,00 6FPF30 1150 1600 Logisnext Danmark A/S 13,00 1 RAL 9005
233090 1,00 6HPF 35 1200 TOYOTA MATERIAL HANDLING 12,00 1 RAL 9005
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232936 1,00 6FPF20 1050 1200 A/S N.P. TRUCKS 10,00 2 RAL 9005
229643 1,00 6FPF45 1300 2400 TMHM FRANCE S.A.S 16,00 2 RAL 9005
229669 1,00 6FPF45 1400 2400 TMHM FRANCE S.A.S 16,00 2 RAL 9005
232870 1,00 2IFOS520 1150 1400 L.T.E. LIFT TRUCK EQUIPMENT S.P.A 14,00 2
232872 1,00 2IFOS520 1150 1400 L.T.E. LIFT TRUCK EQUIPMENT S.P.A 14,00 2
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Fig. 11 Weekly production plan (Karakai, 2023; Author own processing, 2023)

the company's requirements (Karakai, 2023; Aromaa & Väänänen, 2016). This is followed by the necessity to test and verify the functionality of the introduced changes in the company's information system, possibly the correction of errors and the overall evaluation of the modifications. Employee training is also important (Modlo et al., 2019). There is a need to train company employees on the legal use of new system settings and the interpretation of information. The main step is the gradual introduction and deployment in real conditions. Use of existing resources, such as the established Microsoft Dynamics 365 information system, a work terminal in the

Table 1 Main steps of RTPM implementation (Author own processing, 2023)

No	Implementation	Characterisation
1	Planning and preparation	Determination of goals and requirements for the system, identification of necessary resources and personnel for implementation, and preparation of budget and schedule
2	Installation and configuration of the system	System configuration for the needs of the assembly department, including defining monitoring and data collection parameters
3	Functionality testing and verification	Testing the system and verifying its functionality and correcting errors and deficiencies
4	Employee training	Providing training to assembly department employees for proper use and interpretation of information obtained from the system
5	Gradual introduction and deployment	Gradual deployment of the system in real conditions and monitoring of the impact on production performance
6	Evaluation and optimisation	Evaluation of the system's impact on production performance and optimisation of settings to improve its effectiveness
7	Expansion and maintenance	Expansion of the system to other departments and its regular maintenance and updating

assembly department with access to new settings about the RTPM system, display resources and space within the current layout. Last but not least is the evaluation of the impact of the system on production performance and possible optimisation of settings for continuous improvement of efficiency (Young & Rai, 2021). So, it is about maintaining and updating the system within the framework of new challenges and regular updating by current requirements, and it is important to consider the possibilities of expanding this system to other departments within the production company. The individual steps of RTPM system implementation are summarised in Table 1.

7 Conclusion

The proposed solution includes introducing a real-time production monitoring system (RTPM) and integrating it with the existing information system (IS), Microsoft Dynamics 365. It is assumed that the introduction of RTPM and its integration with the IS will increase employees' work productivity and improve product quality. It will also allow the company's management to better monitor and manage production, leading to faster and more efficient decision-making. We could perform a technical

and economic evaluation based on the described solution of implementing smart technologies in the production company. The result of the implementation will be better visualisation and clarity of production data, enabling quick decision-making and identification of problems in real-time. The configuration of the existing corporate information system will also be improved about the department's needs. The gradual introduction of the system in real conditions and constant updating and optimisation of settings will enable continuous improvement of production efficiency. Overall, it can be concluded that implementing smart technologies in business processes can bring significant benefits, and it is important to pay attention to their proper implementation and maintenance to maximise their potential and minimise potential risks.

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Taking Customer-Centricity to New Heights: Exploring the Intersection of AI, Hyper-Personalization, and Customer-Centricity in Organizations

Flor Morton, Teresa Treviño Benavides, and Eduardo González-Treviño

Abstract Customer-centricity has become a buzzword in the business realm, as companies are increasingly aware about the importance of prioritizing customer needs not only to thrive, but also to survive. The digital transformation revolution has introduced novel technologies that have significantly improved the way in which companies gather, store, analyze, and transmit large volumes of data. The convergence of the expanding pool of available data for businesses and the advancements in artificial intelligence offer new possibilities to obtain deeper customer insights and enable swift and hyper-personalized responsive actions. The purpose of this chapter is to analyze how AI, hyper-personalization, and consumer-centricity come together to exert a significant influence on how companies operate today. Additionally, this chapter reflects on the ethical considerations and challenges associated with the use of such technology and strategies. As businesses persist in their efforts to adapt, this exploration sheds light on how AI will shape the future of customer-focused strategies.

Keywords Customer-centricity · Artificial intelligence · Hyper-personalization · Digital transformation · Marketing

1 Introduction

The field of marketing has experienced remarkable transformations. According to Sheth et al. (2000), following World War II, the world witnessed the rise of mass marketing driven by advancements in production technology, communication, transportation, financial resources, and human resources management. There were many

F. Morton (✉) · T. T. Benavides
Department of Management, Universidad de Monterrey, San Pedro Garza García, Mexico
e-mail: flor.morton@udem.edu

E. González-Treviño
Department of Digital and Transformation, Deacero, San Pedro Garza García, Mexico

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needs unmet by the market and consumers were easily satisfied with standardized products at reasonable prices. This era of post-war scarcity evolved into mass production, distribution, and communication, resulting in a society focused on mass consumption. Marketing strategies emphasized promoting, pricing, and distributing products for the mass market, with companies adopting product-centric organizational structures. However, as the market expanded with more players and diverse products, mass market techniques lost effectiveness, leading firms to shift their focus from products to markets. This change gained prominence in the 1950s when the marketing concept was first recognized. Segmentation emerged as a logical response to the growing emphasis on markets highlighting the need for precise alignment of products and marketing efforts with consumer requirements.

In pursuit of gaining a competitive advantage, companies are increasingly working towards being perceived as customer-centric. This emphasis is evident not only in the corporate communications of companies like Amazon and Hewlett Packard, where a prominent emphasis is placed on their dedication to prioritize customers, but also in the inclusion of customer-centricity courses in esteemed business schools, which further underscores the significance of this approach in modern business paradigms (Habel et al., 2020).

In today's business environment, where technology is rapidly changing and offering new opportunities, companies are facing a new era of competition. As more and more digital tools become available, businesses and consumers are more connected than ever before. Organizations now have access to an important amount of data generated by users and their interactions. All this data plays an important role in understanding consumers in an unprecedented manner. For this reason, technology and data play an important role in intensifying competition in the marketplace. Companies are required to adapt, innovate, and provide value to their consumers in order to succeed.

Artificial Intelligence (AI) has revolutionized the field of marketing by providing powerful tools and insights that allow the creation of personalized offers (Davenport et al., 2020; Pradeep et al., 2018), as well as more efficient and effective campaigns (Qin & Jiang, 2019). AI-driven algorithms can analyze vast amounts of consumer data, enabling marketers to understand customer behavior, preferences, and trends on a granular level. This data-driven approach allows for the creation of highly personalized marketing strategies, leading to more relevant and engaging content for consumers.

The use of Artificial intelligence (AI) is changing the way businesses connect with their customers. The intersection of consumer-centricity, artificial intelligence, and hyper-personalization presents a relatively new territory in the literature of business strategy and marketing. While each of these elements has been studied individually before, there is an opportunity to reflect on our understanding of how they interact and influence one another. Therefore, the objective of this chapter is to analyze how AI, hyper-personalization, and consumer-centricity come together to exert a meaningful impact on the way companies operate, as well as to understand how AI will shape the future of customer-focused strategies. Additionally, the present chapter reflects on the ethical considerations and challenges associated with hyper-personalization.

Investigating this intersection could provide insight into how AI can be used to create truly customer-centric experiences that go beyond a simple personalization, but achieving hyper-personalization that offers consumers products and services that match with their preferences. Furthermore, this chapter also contributes to businesses and literature by raising important questions about the ethical considerations and potential challenges of hyper-personalization in the age of AI. Bringing this topic into discussion is crucial for understanding the full potential of these concepts and shedding light on finding a way for more informed and responsible decision-making in organizations.

This chapter is structured as follows: First, the evolution of consumer-centricity through time and the opportunities provided by new digital tools are explored. Next, artificial intelligence is discussed and its role on business strategies is presented. Furthermore, the hyper-personalization concept is analyzed in an attempt to understand its difference from simple personalization strategies, and explore potential challenges and ethical concerns for business. Finally, concluding remarks on the topic are presented to reflect on the future directions of the use of AI for personalization strategies in customer-centric organizations.

2 The Customer-Centric Approach to Marketing

The product-centric paradigm originated from the early days of marketing, companies adhered to a product-centric approach prioritizing production efficiency (e.g., economies of scale) and market share as indicators of profitability (Levitt, 1960; Shah et al., 2006). Back then, companies were more internally focused, emphasizing the creation of excellent products rather than directing their efforts towards catering to the needs of consumers. Subsequently, shifts in the market landscape compelled companies to redirect their attention towards consumers.

Although the concept of customer-centricity dates back to ideas from Drucker (1954) and Levitt (1960), its significance has only been fully embraced by both the academic and business community in the last three decades. Pressures to enhance marketing productivity, high competition, well-informed and demanding customers, market diversity, and rapid technological advances reinforced the need for companies to adopt a customer-centric approach with the recognition that fostering close and profitable customer relationships could offer a difficult-to-replicate advantage (Day, 2000; Sheth et al., 2000).

In the academic realm, there was a growing awareness on the need to study customer-related aspects, including customer service, perceived-quality, satisfaction, and loyalty and several researchers discussed this trends in terms of paradigm shifts in management, encompassing transitions from product-based strategies to customer-centric strategies; hence, conceptualizations of customer-centricity in scholarly works commonly supported the notion of customer-centricity as the antithesis of product centricity (Shah et al., 2006).

According to Sheth et al. (2000), customer-centric marketing prioritizes understanding and meeting the unique needs, desires, and capabilities of individual customers, rather than catering to broad market segments. It involves evaluating each customer individually to decide whether to directly serve them or involve a third party, as well as deciding whether to customize elements of the marketing mix for a specific customer or to create standardized offerings.

Day (2003) argues that customer-centricity refers to the attention placed on the purchaser and on the establishment of customer relationships that are mutually satisfactory, meaning that the company activates its resources in order to create solutions that can satisfy customer's expressed needs. Yet, this approach raises concerns regarding the long-term viability of exclusively prioritizing a customer-centric strategy, suggesting that an approach that balances customer-centricity with a resource focus could be more economically effective (Gummesson, 2008).

Lamberti (2013) is one of the first authors that operationalized customer-centricity and analyzed the organizational factors that influence the adoption of a customer-centric approach. According to this author, customer-centricity is linked to a company's ability to: (1) generate customer intelligence through the collection and analysis of data of customer-firm interactions to support personalized marketing efforts; (2) co-creation (i.g. actively engage customers in marketing and innovation processes); (3) experience marketing (i.g. creating value to the individual self through customer experiences). Therefore, customer-centricity can be considered, according to the author, as a construct with the following four dimensions: (1) interactive customer relationship management (CRM) (an ongoing engagement with customers to gather insights and comprehend both their explicit and concealed needs); (2) customer integration (a systematic inclusion of customers in decision processes related to new product development and marketing); (3) internal integration (well-coordinated organizational structures that gather and disseminate customer information, effectively managing interactions across all touchpoints); and (4) supply chain-integration (the presence of a supply chain that collaborates seamlessly with the company and can accommodate the customization demands posed by customers).

Habel et al. (2020) define customer-centricity as putting customers' interests at the core of a firm's operations by establishing customer-centric organizational structures, adopting customer-centric information technologies, and implementing marketing strategies that are centered on meeting customer's needs. The authors provide a review on the different definitions of customer-centricity in the literature and note that while existing research differs in the nuances of the definition of customer-centricity three characteristics of customer-centricity seem to be well-accepted: the firm as a unit of analysis, an emphasis on the preferences of customers, and the active prioritization of customers. According to these authors, although a few studies explore customer-centricity at a functional level (e.g., customer-centric marketing or customer-focused sales campaigns), previous research has been mainly offered a firm-centered view of customer-centricity, regarding the firm itself as the entity embodying customer-centricity. Also, the definitions of high customer-centricity emphasize a strong dedication to addressing customers' interests even if this involves tailoring considerations to specific customer segments due to variations in interests.

Furthermore, some definitions conceive that customer-centricity involves actively prioritizing customers and their interests above internal firm matters, while other research portrays customer-centricity as adaptations of firm structures and processes to align with customer interests (see Habel et al., 2020 for a review of the definitions of customer-centricity). Yet, none of these studies conceptualized or empirically examined customer-centricity from the customers' perspective. In other words, the way customers perceive customer-centricity. Therefore, in their work, they validated a scale to measure customers' perception of customer-centricity, defined by the authors as the extent to which customers perceive a company to prioritize their interests in all its endeavors.

Apparently, there seems to be clarity and consensus on the fundamental differences between the product-centric and customer-centric paradigms. Traditionally, firms leaned towards being product-centric, prioritizing production efficiency and market share, later this paradigm shifted towards a new paradigm that emphasized the process of dual value creation, both for the company and for the customers (see Shah et al. (2006) for a comparison between product-centric and customer-centric paradigms). However, in both scholarly literature and practical contexts, there is often confusion between the notions of customer-centricity and other marketing concepts. For instance, Gummeson (2008) highlights that marketing orientation is broader in scope than customer-centricity because it encompasses not only customers but also competitors and the way markets function. Sheth et al. (2000) also differentiate customer-centricity from both one-to-one marketing and customer relationship marketing (CRM). The authors note that in contrast to one-to-one marketing, which can be achieved through mass customization by adapting products or offerings (a product-centric approach that positions the product as the initial and focal point of the planning process), customer-centric marketing involves addressing customer needs, wants, and resources as an initial stage of the strategic planning. Furthermore, the distinction between customer-centric and relationship marketing relies on the fact that effective practice of relationship marketing requires a customer-centric approach, but the reverse isn't necessarily true. It is possible to implement customer-centric marketing without fully engaging in relationship marketing.

3 Customer-Centricity in the Digital Age

In the 1980s, the adoption of computing technology sparked a revolution in management and decision-making processes (Heavin & Power, 2018). The democratization of technology, along with the integration of the Internet as an everyday tool, has led to exponential growth in digital data storage and computing capabilities. This has resulted in remarkable improvements in the collection, storage, analysis, and transmission of huge amounts of information. Companies seized the chance to invest in IT infrastructure to facilitate technology-driven customer relationship management, directing substantial investments in CRM software and database marketing, to enable a continuing dialogue across all customer touch points with a personalized treatment;

however, many companies lacked the necessary customer-centric approach to fully capitalize on these opportunities (Shah et al., 2006).

Nowadays, the incorporation of enterprise applications such as Internet of Things (IoT), Machine Learning, Artificial Intelligence (AI) applications, analytics, 3-D printing, virtual, augmented reality, and various other technologies has taken digital transformation and customer-centricity to new levels; this transformation has become a synonymous with competitive advantage and differentiation for companies (Fernández-Rovira et al., 2021). The rapid evolution of technological breakthroughs offers a multitude of advantages, including real-time monitoring, predictive analysis, customization, and decentralized decision support; these factors have fundamentally altered both the operational methods and strategic decision-making processes of organizations (Heavin & Power, 2018; Stalmachova et al., 2022).

The concept of customer-centricity has a long-standing history independent of digitalization, particularly in the fields of marketing and sales. Nevertheless, it has gained renewed interest in the digital age. Riedmann-Streitz (2018) argues that currently, there is a prevalence of customer-centric rhetoric in corporate guidelines, which has made customer-centricity a widely used but vaguely defined concept in various contexts, leading to confusion about who the customer is and what it means to be customer-centric. The distinction between customers and citizens, particularly in the context of public services (e.g., patients, students, parents, etc.), has been a topic of ongoing debate and discussion. The shift towards customer-centric approaches in the public sector, brought with it the idea that individuals receiving public services should be treated as customers with specific needs and expectations. This approach aimed to improve the quality and efficiency of services by applying business-like principles to the public sector. However, as Gummesson (2008), there are inherent differences between customers and citizens that need to be acknowledged. While both groups have needs and expectations, citizens also have broader societal roles and responsibilities, as well as a unique relationship with the government through their rights and obligations as members of a community. For instance, citizens have fundamental needs that extend beyond those typically addressed in commercial interactions and that are essential for a functioning society (e.g., elder care); also, citizens not only have expectations as recipients of services but also have responsibilities as members of a society (e.g., tax payment); moreover, public services are designed to promote the overall well-being of citizens and play a crucial role in maintaining social cohesion and equity; public sector decisions need to consider long-term societal benefits and priorities, which may not align with short-term customer preferences. Balancing these considerations is a challenge for policymakers.

Furthermore, according to Riedmann-Streitz (2018), data has always been essential for CRM systems in the past. However, with the advent of digitalization and the new tools and possibilities that come with it, there has been an increased competition to collect, track, and analyze customer data to better understand and predict customer behavior. Despite companies claiming their commitment and dedication to customers, this prevailing trend underscores a technology-centric approach to customer-centricity, which threatens to reduce customers to mere data points. Therefore, the author contends that a critical reevaluation of customer-centricity

approach is necessary and suggests that this approach can truly benefit people's needs when it embraces a humane and philanthropic focus, respecting individuals' privacy and values. The author proposes a new perspective termed "Humane Customer-Centricity," which combines user-orientation and customer-centricity and shifts the focus towards establishing respectful and emotionally satisfying connections with customers rather than solely relying on technology and data-driven efficiency. This alternative approach proposes observing and anticipating technological and societal developments and understanding people's tasks, challenges, dreams, and needs in both professional and everyday life while at the same time respecting the customer's role, autonomy, and relationship with companies, without completely yielding to technology.

4 Artificial Intelligence and Its Applications

Haenlein and Kaplan (2019) define Artificial Intelligence (AI) as the capacity of a system to accurately interpret external data, acquire knowledge from it, and subsequently apply these acquired insights to accomplish specific objectives and tasks through flexible adaptation. The technologies that enable AI include automation, big data systems, deep learning, neural networks, Natural Language Processing, and Computer Vision. By leveraging these computational tools, AI has the ability to emulate a wide spectrum of human capabilities, ranging from the execution of routine tasks to the complex realms of cognitive thought and emotional processing.

In fact, as proposed by Huang and Rust (2021), rather than conceptualizing AI as a monolithic thinking or as a singular entity, it is more accurate to acknowledge its capacity for diverse intelligences, mirroring the multifaceted cognitive abilities that humans possess. These intelligences can be distinctly categorized (based on their complexity of emulation) into mechanical, thinking, and feeling. Mechanical AI is specifically designed to automate routine and repetitive tasks such as machine translation, classification, and clustering algorithms, among others. The purpose of Thinking AI is processing unstructured data to derive novel insights and decisions by recognizing patterns and regularities, exemplified in applications like text mining, speech recognition, and facial recognition, often implemented through machine learning, neural networks, and deep learning. Meanwhile, Feeling AI is geared towards facilitating two-way interactions involving human and analyzing human emotions, employing technologies like sentiment analysis, natural language processing (NLP), text-to-speech conversion, recurrent neural networks (RNN), chatbots for human-like communication, embodied and embedded virtual agents for human interaction, and specialized hardware equipped robots for detecting emotional cues.

Furthermore, AI extends beyond the mere emulation of human capabilities, having evolved to enhance human abilities (Wang & Siau, 2019). Advancements in AI technology have brought about transformative changes across various sectors, promising to disrupt traditional practices and significantly enhance outcomes. One such arena

witnessing remarkable progress is the realm of self-driving vehicles, where AI-powered systems hold the potential to revolutionize road safety (Bharadiya, 2023; Meyer-Waarden et al., 2022).

In the medical field, AI is increasingly being utilized for diagnostic purposes, harnessing its capability to analyze vast amounts of patient data. This application anticipates patient readmissions, suggests optimal treatment strategies, and proactively identifies potential health risks (Rajkomar et al., 2019). Additionally, the healthcare sector has witnessed profound changes, with AI augmenting patient monitoring mechanisms and even facilitating intricate surgical procedures (Hamet & Tremblay, 2017).

Dwivedi et al. (2021) suggest that AI plays a pivotal role in education by serving as an intelligent tutor, offering personalized instruction, and providing automated grading solutions. These tools empower educators to prioritize qualitative teaching while digital platforms powered by AI can enhance understanding and prediction of student behaviors, ensuring timely pedagogical interventions. Notably, AI's impact extends to special education, where it significantly enhances accessibility and interactivity for learners with disabilities. This multifaceted influence of AI underscores its capacity to reshape diverse sectors, improving safety, healthcare outcomes, educational experiences, and inclusivity, among numerous other aspects of society.

4.1 AI and Customer-Centricity

AI has made important inroads in the realm of business, profoundly influencing the way organizations operate and strategize (Heavin & Power, 2018; Stalmachova et al., 2022). AI's application within business contexts often centers on automating tasks and functions, and this is no exception in the field of marketing. Customer-centricity, emphasizing the alignment of business strategies to customer needs, has been significantly influenced by technology and data. Vishnoi et al. (2018) emphasize the significant transformation of new technology in marketing strategies, marking the transition from traditional technologies to more advanced, data-driven approaches. Merging customer-centricity with data centricity, allowing business a more personalized marketing approach.

One prominent area where AI has demonstrated its influence is in data analytics. AI-driven data analysis tools have empowered businesses to process vast amounts of information swiftly and accurately (Fernández-Rovira et al., 2021). This not only aids in making informed decisions but also enables companies to unearth valuable insights that might have remained hidden in the past.

Huang and Rust (2021) point out that in the marketing context, Mechanical AI is primarily used for big data collection, while Thinking AI is instrumental in conducting detailed market analysis from data sets, and Feeling AI is employed to understand customer emotions and insights. In the realm of strategy, AI assists in

decision-making processes related to segmentation, pricing, and product personalization. Therefore, AI algorithms can analyze customer data to predict purchasing patterns, allowing businesses to tailor their marketing strategies more effectively.

AI has also revolutionized customer service. Chatbots and virtual assistants, powered by AI, provide 24/7 support, addressing customer inquiries and resolving issues precisely when the customer needs assistance and in a way that emulates human interaction. This has not only been found to enhance customer satisfaction in certain consumption situations (Chung et al., 2020; Jiang et al., 2022) but also streamline business operations by reducing the need for human intervention in routine tasks. Additionally, AI has opened up new horizons in product development and innovation (Bahoo et al., 2023; Verganti et al., 2020). It can generate product recommendations based on customer preferences and feedback, facilitating the creation of offerings that resonate more closely with market demands (Pradeep et al., 2018). Furthermore, AI tools have increased firm's capacity to anticipate customers' needs, not only by offering goods and services aligned with those needs, but also by predicting the optimal price to charge and the promotions or discounts that best suit their customers (Davenport et al., 2020), as well as tailoring messages in a more personalized and almost imperceptible manner (Deng et al., 2019; Kietzmann et al., 2018).

5 Ethical and Regulatory Challenges of the Use of AI in Business

The capabilities of AI pose ethical and regulatory challenges. Considering the power of AI technologies applied to marketing fields, customer vulnerability requires regulatory policies and users' awareness regarding the use of new powerful technologies for business (Morton & Vázquez-Maguirre, 2024). For instance, Campbell et al. (2022) highlight the growing issue of manipulated ads in the digital world. AI techniques, like deepfakes and Generative Adversarial Networks (GANs), now enable the creation of personalized and realistic fake ads. These ads are exceptionally well-crafted and can easily fool consumers, making it hard for consumers to tell if an ad is real, and affecting how persuasive they find it.

Buolamwini and Gebru (2018) consider that a primary concern is the bias that can manifest in AI systems. While AI algorithms, by design, don't possess inherent biases, they are trained on historical data that might be tainted by past prejudices. This can lead AI systems to inadvertently echo or even intensify these biases, potentially resulting in distorted and unjust outcomes. Moreover, the lack of transparency in many AI decision-making processes commonly referred to as the "black box" phenomenon raises pivotal concerns about trust and understandability (Castelvecchi, 2016). Such lack of clarity can affect users, thereby limiting the adoption of AI technologies (Burrell, 2016).

Dignum (2018) suggests that as autonomous decision-making capabilities scale in business domains, it is essential to evaluate the accountability involved in decisions made by these algorithms. AI systems, regardless of their autonomy, social awareness, and learning capacity, are human made tools designed to achieve specific objectives. It is therefore crucial to consider societal, moral, and legal values into every phase of AI development. Professionals using these capabilities for business outcomes should have guidelines to shape the design, regulate boundaries, ensure responsible data management, and empower individuals to decide their level of engagement with these solutions. Therefore, the ultimate challenge isn't merely about architecting ethical AI but ensuring its alignment with the core values and principles of society.

6 Hyper-Personalization as a Business Strategy

The term "hyper-personalization" has recently been addressed in both businesses and literature, and makes reference on how companies can now deliver experiences to their customers in a way that products and services are tailored individually. Specifically, hyper-personalization has been defined as a strategy that relies on the company's capability to gather and transform customer data into personalized experiences (Valdez Mendia & Flores-Cuautle, 2022). Furthermore, these unique shopping experiences deliver more value and drive engagement, loyalty, and revenue. In other words, hyper-personalization enables companies to deliver tailor made communications to shoppers according to what they have bought, what they've browsed, and what they've clicked on in an email, website, or social media (Shukla & Nigam, 2018).

6.1 Personalization Versus Hyper-Personalization

Personalization is a concept that marketers are increasingly using to improve their performance, but the lack of agreement regarding its meaning limits successful communication and cooperation between service providers and marketers (Vesanen, 2007). One of the main challenges regarding this topic is the real difference between personalization and hyper-personalization, as they are both marketing strategies that aim to deliver more relevant and unique content and experiences to customers. However, there is a distinction between the two strategies in terms of their depth and degree of customization. On one hand, it is known that personalization involves customizing marketing content, messages, or recommendations based on known customer data, preferences, and behavior. It uses data such as demographics, purchase history, browsing history, and location to segment and target customers with content and offers that are more likely to resonate with them (Vesanen & Raulas, 2006).

Personalization in service encounters has proven to be one of the most important determinants of perceived service quality, and of customer satisfaction and other patronage indicators (Mittal and Lassar, 1996). On the other hand, hyper-personalization takes personalization to a more advanced level by leveraging real-time data, using sophisticated algorithms. A hyper-personalization strategy relies on the company's capability to gather and use customer data into personalized experiences (Valdez Mendia & Flores-Cuautle, 2022). First, it involves collecting and analyzing data from various sources, including behavioral data, social media interactions, and even IoT (Internet of Things) devices. While such data is collected, hyper-personalization strategies require the use of machine learning and AI to deliver highly individualized and context-aware experiences to each customer. One of the big advantages of achieving hyper-personalization, is that customers can receive real-time content, and create a unique experience. In this case, the "segment" is each individual customer who receives an immersive and engaging experience by providing content and recommendations that are incredibly specific to each individual's preferences and behaviors.

Despite the hyper-personalization term is well known in marketing practice, there is scant literature on the topic. Research addressing the topic has explored the requisites and outcomes of hyper-personalization strategies. For example, literature has suggested that a hyper-personalization strategy requires four elements: data foundation, decisions, design, and distribution. Data foundation is perhaps the most important and the starting point, as customer's information and feedback are required to deliver the experiences (Valdez Mendia & Flores-Cuautle, 2022). Additionally, Rosenbaum et al. (2019), analyzes the impacts of hyper-personalization strategies in wellness products such as facial serums, custom-prepared meals, vitamins, etc. Results suggest that consumers believe that hyper-personalized products are worth premium prices, regardless of their desire to own these products. Another study analyzed hyper-personalization strategies in Websites, in a way that users can receive a personalized version of an e-commerce website in the fashion industry, using big data analytics. Results suggest that online users reported a higher perceived usefulness of such Websites. Overall customers showed more positive experiences and positive associations with the company, which are two variables that play an important role toward the customer behavioral intention. This research is important, as it suggests that hyper-personalization online has an impact on the online consumer buying behavior (Jain et al., 2018).

6.2 Examples of Hyper-Personalization Strategies

There are many examples of how customer data can be used to deliver unique hyper-personalized experiences to customers both online and offline. One of the most common strategies is to offer personalized product offerings and recommendations for each user on online sites (Valdez Mendia & Flores-Cuautle, 2022). For example,

Table 1 Examples of hyper-personalization strategies

● Personalized product offers and recommendations
● Dynamic websites for individualized online experiences
● Dynamic pricing
● Email recommendations and deals
● Location-based recommendations
● Online content personalization
● Online personalized assistance
● Abandoned cart strategies
● Real-time inventory updates
● Loyalty programs
● Post-purchase service
● Display and search advertising
● In-person customer experience

Source Own elaboration based on Valdez Mendia & Flores-Cuautle (2022)

Amazon is known for having "Customers who bought this also bought" and "Recommended for you" sections in its website. These product recommendations are unique for each user, and are based on the person's—and other similar users—browsing history, purchase habits, and online behavior. Overall, the analysis that Amazon makes, enables them to show highly relevant products to individual users.

Furthermore, pricing strategies can also benefit from hyper-personalization, by offering dynamic prices that consider factors such as demand, supply, and consumer behavior to adjust prices in real-time. The price is calculated and optimized in a way that the likelihood that the individual user makes a purchase is increased (Valdez Mendia & Flores-Cuautle, 2022).

On the offline channel, customer's experiences can also be enhanced by hyper-personalization. One recent study addressed the use of artificial intelligence technologies in physical stores to better understand customers. Particularly, facial expression recognition, automatic age and gender recognition, and in-store customer tracking capabilities have proven to contribute to a retailer's competitive advantage by providing hyper-personalized services and products to its customers, and ultimately improve on-site customer's experiences (Micu et al., 2022). Table 1 offers examples on the most common hyper-personalization strategies supported by AI.

7 Hyper-Personalization Ethical Concerns & Challenges

Despite the advantages of hyper-personalization strategies for organizations, there is a need to recognize that achieving such levels of personalization is not an easy task. There are some challenges that require attention and in some cases the implementation of technology and processes. One of the main challenges is linked to the most important part of hyper-personalization: data. The data relies on the heart of such strategy, therefore, obtaining precise and quality data is the foundation upon which

the personalized experiences are built. As Valdez Mendia & Flores-Cuautle (2022) suggest, data foundation is one of the most important parts of hyper-personalization. To obtain data requires companies to think about data privacy and ethics, as well as regulations that limit or prevent companies from collecting, storing and using customer data without user's consent. The ethical part of such practices has been discussed in both literature and practice. Particularly, the collection of user data has been criticized and even classified as unethical. On one hand, some experts believe that there is a high risk that customers will reject companies that have non-transparent data collection and use practices. On the other hand, other groups of experts have suggested that people are ready to sacrifice privacy to obtain convenience in better products, services and technologies (Gabisch & Milne, 2014; Gordiyevskaya, 2020; Shaw & Sergueeva, 2019). Recent research on the topic has found that most Internet users do not see a direct and potential threat to their privacy by data collection strategies of organizations. However, users would like to reduce the amount of personal information that companies receive (Gordiyevskaya, 2020). Companies need to rethink how data is being collected, and be completely transparent with users about how they are obtaining and using such information.

Another challenge regarding hyper-personalization strategy comes with the quantity and quality of data. A single interaction, click or behavior by itself may not have meaning or much importance. What makes a difference in hyper-personalization is the aggregation of a vast amount of information. Companies may need to understand and rethink how to integrate data from multiple sources to achieve a complete view and understanding of customers. Additionally, all this data comes quickly and in an incredible amount, so appropriate storage and management may need to be implemented as well. Overall, the technical and process challenges associated with hyper-personalization can be complex, which will often require a specialized team to lead the company throughout this process.

8 Outcomes of a Customer-Centric Approach

Achieving a consumer-centric approach in organizations has proven to have an impact in business. An emerging body of literature is focused on the outcomes of adopting a customer-centric approach, revealing compelling evidence of its positive impact on company performance. For instance, research indicates that implementing a customer-centric organizational structure can lead to heightened levels of customer satisfaction (Lee et al., 2015), strengthened customer relationships (Jayachandran et al., 2005), increased supplier sales and profits (Crecelius et al., 2019), and improved operational performance (Chavez et al., 2016). Furthermore, the perception of customer-centricity has also been linked to increased customer loyalty and higher customer revenue (Habel et al., 2020).

Amid the ever-evolving economic context, even for thriving companies, the continuity of their success in the future remains uncertain. Hence, at the core of marketing

lies the crucial ability to anticipate both customer and competitor behaviors, a practice known as "anticipatory management," which can confer a distinct competitive advantage upon organizations by proactively identifying and preparing for upcoming trends for an effective planning (Sheth et al., 2000). A common element that runs through various conceptualizations of customer-centricity is the emphasis on generating customer insights to guide a company's strategic decisions, research indicates that points to a favorable correlation between customer insights and business performance (Varadarajan, 2020). For example, the adoption of an outside-in approach in developing strategies, characterized by leveraging market insights and a profound understanding of customer needs has been associated with the achievement of firm success and competitive advantage (Day & Moorman, 2011; Mu et al., 2018). For instance, Srivastava et al. (2001) presented a framework which emphasized how firms can attain competitive advantage and superior financial performance by leveraging their market-based assets (e.g., relational and intellectual) to provide exceptional customer value. Later, Riedmann-Streitz (2018) complemented the framework by outlining the relationship between a firm's customer information assets, their ability to analyze this information, resulting in customer insights, marketing strategy, and overall business performance.

Despite the evidence of positive outcomes generated by customer-centricity, in an attempt to understand why some companies fail to achieve the expected performance improvements of customer-centricity, Lee et al. (2015) tested a model. This model indicated that, on one hand, a firm's customer-centric structure enhances performance by increasing customer satisfaction, but on the other hand, it can also diminish performance by adding coordination costs. Therefore, the overall performance impact of customer-centricity relies on whether the external benefits generated surpass the internal expenses accrued. The authors also found that the unique advantage derived from a customer-centric approach can diminish when numerous competitors likewise adopt customer-centric structures and effectively address customer needs. This reduction in competitive advantage also occurs when only a limited number of customers seek increased customization and responsiveness. Consequently, it is advisable for managers to thoroughly assess their competitive landscape to avoid misguided expectations about the returns of transitioning to a customer-centric structure.

Overall, this chapter suggests that a consumer-centric organization can be enhanced by the integration of Artificial Intelligence to create hyper-personalized interactions with customers. Taking this into consideration, AI-driven hyper-personalization as marketing strategies enables businesses to put the customer at the center of their operations, delivering not just products or services, but a truly personalized journey that delights customers and could potentially improve business performance.

9 Conclusions

The impact of AI on businesses is multifaceted, touching upon various aspects of business operations and decision-making processes ranging from data analytics and customer service to product development. AI algorithms can analyze customer data to predict purchasing patterns, allowing businesses to tailor their marketing strategies more effectively. This not only assists in informed decision-making but also empowers companies to discover valuable insights that could have remained concealed previously. As AI continues to evolve, it is likely that its influence on businesses will only grow, shaping the future of commerce in unprecedented ways.

Achieving hyper-personalization in organizations can deliver unique shopping experiences. Organizations can harness hyper-personalization as a competitive advantage by creating their products and services to meet the unique needs and preferences of each customer. By employing AI and data analytics, businesses can gain deep insights into individual behaviors of their customers. This enables them to provide not just personalized recommendations, but also timely content that better resonates with their consumers. This heightened level of customization—or hyper-personalization - may foster stronger customer loyalty. Moreover, by continually adapting and evolving their hyper-personalization strategies, organizations can stay ahead of competitors, positioning themselves as market leaders who truly understand their customers' desires.

Figure 1 is a representation of how artificial intelligence and hyper-personalization can converge in an organization with a customer-centric approach. The customer-centric approach, as previously mentioned, requires the prioritization of the customer needs. Hence, the identification of consumer insights to generate strategies should be at the heart of the organization. Consumer data is an essential input for Mechanical AI, Thinking AI, and Emotive AI to enable a deep understanding of consumers (insights). Such AI capabilities are able to generate more consumer data as well as empower personalization strategies to a new level—hyper-personalization, by offering unique products, services, and interactions that can resonate with consumers on a deeper level. Furthermore, hyper-personalized business strategies and operations can generate more consumer feedback (data) and other business outcomes are again collected, analyzed, and interpreted by AI, which can be later used to improve and optimize hyper-personalization strategies as well as to generate more consumer insights.

In conclusion, the exploration of how consumer-centricity, artificial intelligence, and hyper-personalization intersect in today's organizations, this chapter has revealed the potential landscape in today's business environment. By analyzing how AI technologies can be harnessed to deliver hyper-personalized experiences, it becomes evident that companies are not only meeting the evolving expectations of their customers but also redefining the very essence of customer-centricity and personalization. The profound impact of these three pillars working together is evident, as we see more enhanced customer experiences, strengthened brand loyalty, and substantial revenue growth.

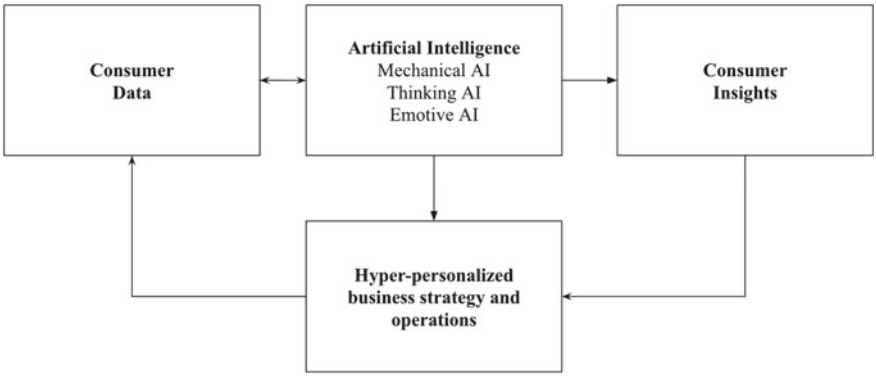

Fig. 1 AI and Hyper-personalization in Customer-centric organizations. *Source* Own elaboration based on the literature reviewed in this chapter

However, as we explore the use of artificial intelligence to achieve hyper-personalization, ethical considerations arise. The chapter has discussed the ethical challenges associated with this phenomenon, emphasizing the need for businesses to find a balance between delivering tailored experiences and considering individual privacy. As artificial intelligence continues to permeate the business landscape, it is important for companies to maintain awareness of such ethical concerns and the reinforcement of regulatory policies to ensure its responsible use becomes necessary.

Overall, this chapter attempts to advance in the discussion of the use of AI, hyper-personalization, and customer-centricity in organizations. Future research on hyper-personalization and artificial intelligence in organizations are promising. Exploring the effects and impacts that hyper-personalization strategies have on consumer behavior and other marketing variables such as brand loyalty and purchase intention will be necessary as strategies operate through time. These strategies can be analyzed in terms of type and size of companies, as well as for different types of consumers, products, and services. Additionally, the ethical concerns that emerge from data collection and use will continue to be a topic of interest, as companies will certainly need roadmaps to understand best practices in the implementation of a hyper-personalization strategy driven by AI.

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Contribution of Industry 4.0 Technologies in Adopting Metrology 4.0 in Manufacturing Industries

Jailos Mrisho Nzumile, Victoria Mahabi, and Ismail W. R. Taifa

Abstract The digitalisation of metrological practices is paramount to ensure its full integration to enable various aspects, such as smart factories, online inspections, and real-time calibration, among others, in the manufacturing industry. The study explores various contributions of Industrial Revolution (IR4.0) technologies in digitalising metrological services, the interface between Metrology 4.0 (M4.0) and IR4.0, and M4.0 adoption factors. After the screening process, fifty-six scientific publications from Scopus, Open Science, ScienceDirect, and Google Scholar databases were involved in the study. It was found that the development of M4.0 and IR4.0 influence one another. For example, deploying inline metrology is critical to ensure real-time inspection, problem identification, and rectification to enable smart factories. Several critical factors were also identified to enable developing countries to adopt M4.0. The factors include the availability of a skilled workforce, infrastructure, management commitment, awareness of IR4.0 technologies, flexible organisation culture, investment capital, M4.0 standards, and norms for widespread adoption. Moreover, the study found several contributions of IR4.0 technologies in digitalising metrological practices in manufacturing industries, such as the inspection process, calibration of industrial measurement instruments, testing, traceability, and process monitoring. Among the IR4.0 technologies, three major contributors to digitalising several metrological practices, including the Industrial Internet of Things (IIoT), Big data analytics, and artificial intelligence. Technologies such as cyber security, autonomous systems, and additive manufacturing are essential to ensure M4.0 adoption, thus necessitating future studies on their contribution to the adoption process. It is paramount for developing countries to set a systematic roadmap or framework that considers a holistic paradigm shift to a new metrology approach than adopting solution-based metrological practices.

J. M. Nzumile
Department of Legal and Industrial Metrology, College of Business Education (CBE), Dar es Salaam, Tanzania

J. M. Nzumile · V. Mahabi · I. W. R. Taifa (✉)
Department of Mechanical and Industrial Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania
e-mail: itaifa@udsm.ac.tz; taifaismail@yahoo.com

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1 Introduction

The term Industrial Revolution (IR) can be described as the economic dominance transition from farming and handcrafting to a manufacturing and industrialised economy. The IR began during the 18th Century, in which Britain was the first country to be industrialised (Britannica, 2023; Taifa et al., 2020, 2021b). The 1st industrial revolution (IR1.0) was mainly characterised by using steam engines to mechanise manufacturing industries' production process, which was initially done by muscle power (Asghar et al., 2020; Nhelekwa et al., 2022). During the second industrial revolution (IR2.0) in the 19th Century, massive inventions of multiple technologies were witnessed, including electricity, chemical industries, alloy, internal combustion engines, petroleum industries, telegraph, telephone, and radio (Mohajan, 2020). The IR2.0 resulted in mass production and assembly lines which were enhanced by precise and automatic rapid production machines (Maganga & Taifa, 2023a, 2023b, 2023c, 2024; Taifa & Vhora, 2019).

The advent of the third industrial revolution (IR3.0) began to take place in 1950 (20th Century) and was considered the transformation from mechanical and analogue electronics into digital electronics (Mohajan, 2021). The technologies such as mainframe computers, three-dimensional (3D) printing, robotics, semiconductors, renewable electricity, e-commerce, smartphones, and microprocessors are among the notable inventions in the IR3.0 (Gordon, 2013; Mahojan, 2021). Since 2011, the emergency of the fourth IR began to occur, characterised by digitalisation and integration into cyber-physical systems (CPSs) (Souza et al., 2021). The sophisticated and advanced technologies are the key pillars of the fourth industrial revolution (IR4.0), which include the Internet of Things (IoT), additive manufacturing, artificial intelligence (AI), machine learning, autonomous robots, vertical and horizontal systems' integration, virtual and augmented reality, intelligent sensors, and big data analytics, computer simulation, virtual factories, smart manufacturing, dark manufacturing, cloud computing, quantum computing, genetic engineering, blockchain technologies, among others (Nhelekwa et al., 2022; Taifa, 2020).

The nascent technologies in IR4.0 have triggered massive changes in multiple fields of science and technology, resulting in several neologisms aligning with IR4.0, such as metrology 4.0 (M4.0), quality 4.0 (Q4.0), construction 4.0 (C4.0), agriculture 4.0 (A4.0), fashion 4.0 (F4.0), textile 4.0 (T4.0), lean manufacturing 4.0 (LM4.0), oil and gas 4.0 (O&G4.0), among others (Cunha & Santos, 2020; Maganga & Taifa, 2023c, 2024; Ngowi, 2020; Nhelekwa et al., 2022; Taifa, 2020). Metrology 4.0 is an advancement of metrological activities leveraging IR4.0 technologies that involve digitalisation and integration into CPSs (Cunha & Santos, 2020). The application of IR4.0 technologies in M4.0 has and/or will revolutionise techniques, methods, and

procedures in undertaking metrological activities including real-time calibration, in-process metrology, inline quality inspection, touchless calibration, and digital calibration certificate (DCC) among others (Andonov & Cundeva-Blajer, 2018; Azamfirei et al., 2023; Cunha & Santos, 2020; Eichstädt, 2020; Rubel et al., 2022).

Considering the disruptive nature of the IR4.0 technologies in multiple fields of science, this study explores various contributions of IR4.0 technologies in the digitalisation of metrological services (M4.0) in the manufacturing industries. A systematic literature review (SLR) is conducted regarding the current trends in metrological services in which IR4.0 technologies are being applied. Moreover, the study aims to address the following number of research questions (RQ).

RQ1: What is the interface between M4.0 and IR4.0?

RQ2: What are the factors to consider in adopting M4.0?

RQ3: How can IR4.0 technologies contribute to adopting M4.0 in manufacturing?

The general structure of the study encompasses several sections as follows. Section 1 entails a research background describing the historical underpinning of IR4.0 and its association with M4.0 and research questions. The descriptions of the systematic literature review are covered in Sect. 2, while the methodology is presented in Sect. 3. Results and discussion regarding the IR4.0 contributions to M4.0 are presented in Sects. 4 and 5, respectively, whereas Sect. 6 presents the study's concluding remarks, recommendations, and future research.

2 Theoretical Orientations

The fourth industrial revolution (IR4.0) concept was formally introduced in Germany, where a group of scientists, business practitioners, government, and other stakeholders intended to increase competitiveness in several sectors of the economy (Kumar et al., 2022). The improvements were to digitally connect products, value chains, and business models through the use of innovative and enabling technologies such as the Internet of Things (IoT), blockchain, virtual reality (VR), augmented reality (AR), 3D printing, artificial intelligence (AI), cloud computing, big data analytics, and cyber-physical systems (CPSs) (Ghobakhloo, 2018; Kamble et al., 2018; Veile et al., 2020). The employment of these state-of-the-art technologies in multiple sections within the manufacturing industry and other sectors can revolutionise the entire process, providing a real-time solution, real-time data collection and analysis, decentralise decision-making, and seamless communication of the entities within and outside the processes (Kamble et al., 2019).

Madakam et al. (2015) defined IoT comprehensively as the integrated network of objects capable of auto-organising, sharing information, resources, and data, and reacting and acting upon a particular situation or environmental change. In the information technology world, IoT is maturing and continues to be the latest and hype concept and is considered a global network allowing the integration into CPS

(Madakam et al., 2015). The IoT's enabling technologies vary as per domain and scenario; thus, they are being categorised based on their functionality in IoT within the five-layer model such as the perception (objects) layer, network layer, middleware layer, application layer, and business layer (Alsubaei et al., 2018; Mwangaila et al., 2023).

The National Institute of Standards and Technology (NIST) defines cloud computing as the technology enabling ubiquitous and convenient access to a shared pool of configurable computing devices that can be rapidly provisioned with minimum management. Cloud computing offers the accessibility and use of virtualised resources that can be reconfigured dynamically to adjust to a variable load while enabling optimum resource utilisation (Voorsluys et al., 2011). Cloud computing enables the networking of multiple entities within an organisation over the Internet. Employing technology in manufacturing industries will unleash the full potential in the production process, leading to increased data sharing, improved system performance, and cost reduction (Kamble et al., 2018; Liu & Xu, 2017).

Computer simulation in IR4.0 utilises real-time data to mimic and mirror the real-world environment in a virtual model that includes machines, products, or humans (Taifa, 2020). Simulations in the IR4.0 perspective enable testing and optimisation of process parameters in a virtual environment before embarking on the actual process, thus leading to set-up time reduction and quality process output (Bahrin et al., 2016; Kamble et al., 2018). A 3D printing technology, referred to as additive manufacturing, utilizes computer-aided design (CAD) software to generate a 3D model, which is then printed on a 3D printer as a form of liquid or particle. In additive manufacturing, an object is created by building up a successive layer of material, negating the need for part assembly as in subtractive manufacturing, thus saving time and increasing accuracy and cost (Maganga & Taifa, 2023a). Integrating millions of sensors and communication devices involving large amounts of data processing in the IR4.0 era requires a reliable security system. Cyber security in the FIR provides security from cyber-attacks and data theft, preventing defective parts or system shutdowns (Wittenberg, 2016).

An autonomous system integrated into the process provides flexibility, interaction, and cooperation between multiple entities in accomplishing a particular task. It offers a cost advantage, a wide range of capabilities, individualized operation, and flexibility with embedded safety systems (Pei et al., 2017). Artificial intelligence (AI), sometimes machine learning (Mwangaila et al., 2023), is also a significant pillar in IR4.0. It is a software system based on a neural network enabling the recognition of voice and image. With this capability, AI enables detailed examination to predict system failure and inform users to take necessary steps (Maganga & Taifa, 2023a). Big data refers to a big and complex data set that requires to be collected and analysed using specified software. The collection of large amounts of data and their comprehensive evaluation from different sources is enabled by using big data analytics in IR4.0, enhancing real-time process monitoring (Maganga & Taifa, 2023a).

Augmented and virtual reality enables the interaction and perception of humans and their surroundings. They integrate a computer-generated object with the real world to enable the simulation, analysis, and decision before the actual process.

With augmented reality (AR), virtual objects and information are integrated into the real world, unlike virtual reality, where a completely virtual object and environment are integrated (Reljić et al., 2021).

The technologies in IR4.0 have a promising future in multiple fields of science, business, economy, and industry, among others. Several researchers performed numeral studies related to metrology 4.0 in the context of Industry 4.0. Research conducted by Maganga and Taifa (2023a) conceptualised Q4.0 as an emerging quality management concept for manufacturing industries aiming at identifying adoption factors and IR4.0 leveraging technologies. A transition framework developed by Maganga and Taifa (2023b) based on People-Process-Technology (PPT) also signifies the potential of exploiting IR4.0 technologies in producing quality goods. Likewise, Maganga and Taifa (2023c) established the readiness of Q4.0 in the manufacturing industries. Kang et al. (2016) also performed a study on smart manufacturing in the context of IR4.0, describing the past and present conducts and predicting its future, whereby they suggested that future studies should lay down strategies to apply smart manufacturing technologies throughout the product life cycle. In fact, the entire product life cycle should be considered as the means of achieving the total productivity and massive transformation (Mwasubila et al., 2022; Athuman et al., 2024; Danguche & Taifa, 2023). Thus, reference models and application guidelines on the application of IR4.0 technologies on each product life circle step should be set in the future. Junaid et al. (2022) also conducted a study on the use of metrology techniques to produce high quality and waste reduction, wherein they came up with a high-precision metrology system to measure the dimensions of parts in real time during the manufacturing process.

3 Methodology

A qualitative approach was used to analyze the contribution of IR4.0 technologies in adopting M4.0 in manufacturing industries. Bibliometric and content analysis was performed to identify various factors for M4.0 adoption and their contribution using a visual analysis tool, i.e., VOSviewer software.

3.1 Inclusion and Exclusion Criteria

In the selection of materials for this study, the time frame for article publication was considered, in which articles published from 2011 up to 2023 were included. The inclusion criteria for paper selection were review articles, research articles, and conference papers. On the other hand, books, newspapers, non-full articles, non-relevant studies, medical articles, non-English articles, and duplicate papers were excluded. The PRISMA flow chart for the systematic literature is presented in Fig. 1 (Athuman et al., 2024; Taifa, 2021; Taifa et al., 2021a, 2021b).

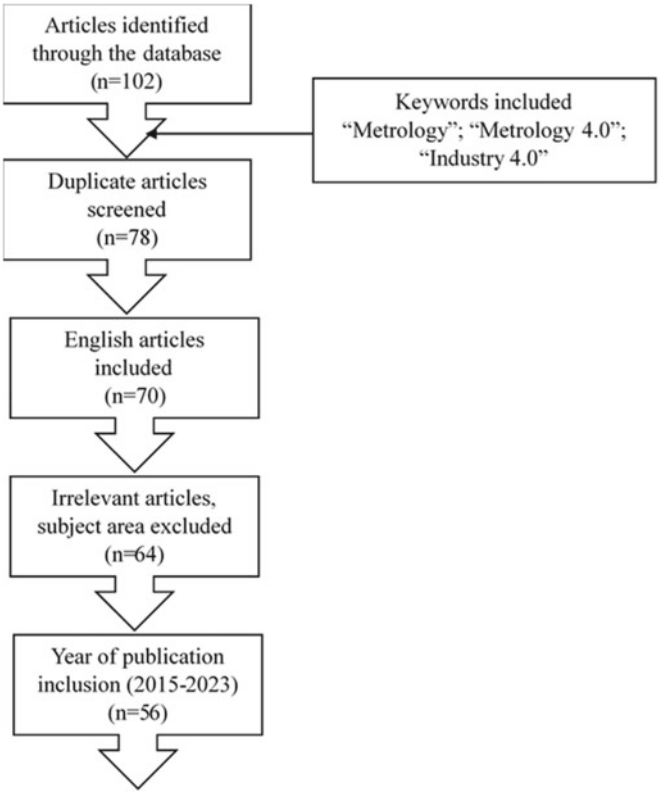

Fig. 1 Article screening flow diagram. *Source* Created by the authors

3.2 Information Sources

Considering the nascent of the M4.0 concept in the context of IR4.0, the materials for this study were extracted from Open Access, ScienceDirect, Google Scholar, and Scopus databases. The search was guided by several keywords, including "Industry 4.0", "Metrology 4.0", "Manufacturing", and "Metrology". Nevertheless, related papers with the keyword quality 4.0, inspection, and measurement were also included to ensure the reliability and accuracy of the research results obtained.

3.3 Bibliometric Analysis

The statistical analysis of articles, book chapters, and related material was performed to track author contribution, year of publication, co-authorship and co-occurrence.

This analysis provides a deeper understanding of the M4.0 concepts, its inception into the Industry 4.0 context, and current trends in the manufacturing industries.

3.4 Literature Content Analysis

The overall summary and synthesis of the findings regarding the articles selected were performed through thematic and content analysis. The analysis focused on the adoption factors for M4.0 and the contribution of Industry 4.0 technologies in adopting M4.0 in manufacturing.

4 Results

The bibliometric and literature contents analysis results are presented in Sect. 4, and the discussion on the contribution of IR4.0 technologies in adopting M4.0.

4.1 Bibliometric Analysis

The bibliometric analysis was conducted firstly by collecting the selected articles in Portable Document Format (PDF) format, introducing them to Mendeley software and converting them into an RIS file. The converted file was then inserted in *VOSviewer* for analysis. Two analyses were conducted in the software, including co-occurrence, wherein the occurrence of multiple keywords in multiple studies was considered. The second analysis was conducted for co-authorship, where the most productive authors and their interrelation were depicted.

4.1.1 Co-occurrence

The co-occurrence indicates multiple keywords that have been repeatedly mentioned in several articles depicting the core contents of a scientific publication. It describes the keyword's relationship regarding a concept they are dealing with. The analysis presents a network of subjects grouped into interconnected clusters. A total of eight (8) clusters, one-hundred eight five (185) links with five hundred thirty-one (531) link strength has been identified from the analysis as indicated in Fig. 2. The clusters include Industry 4.0, metrology, digital twin, quality management, machine learning, deep learning, robotics, and the Internet of Things.

The Industry 4.0 cluster is observed to be the centre of the network. It connects the entire clusters, indicating that it is the most frequent concept in the scientific publications analysed, as indicated in Fig. 3. Moreover, it indicates that most of the

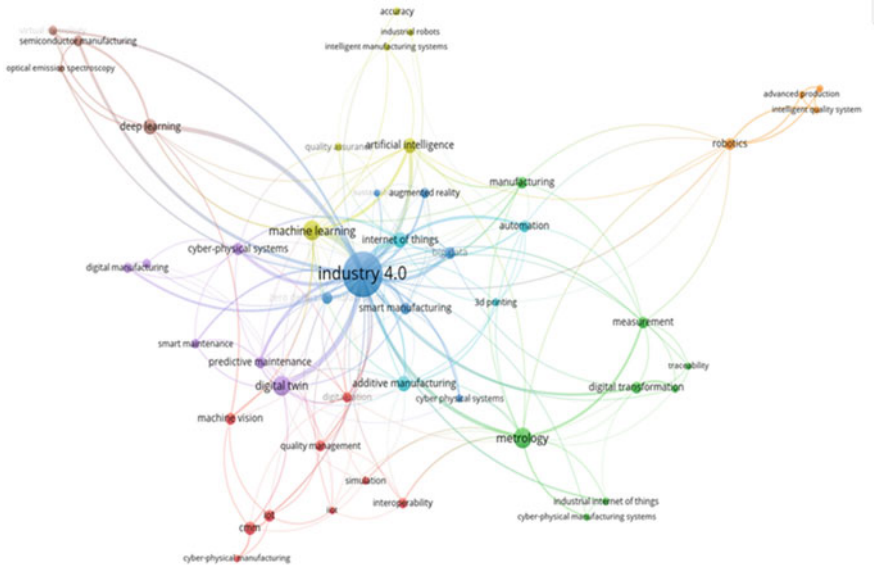

Fig. 2 Mapping of overall clusters in VOSviewer. *Source* Created by the authors

scientific publication focuses their main ideas on the Industry 4.0 paradigm as it contains thirty-nine (39) links, two hundred twenty-two (222) links' strength with one hundred thirty-seven (137) occurrences. Normally, in the diagram, the thicker the link line, the higher the connection between the two items. Hence, Fig. 3 indicates that Industry 4.0 is very much connected to several items, including machine learning, digital twin, deep learning, metrology, artificial intelligence, and CPSs.

Metrology cluster is the second most researched concept to Industry 4.0 with twenty-eight (28) occurrences and fifteen (15) links, as indicated in Fig. 4. Within this cluster, several keywords have been identified, including Industry 4.0, cyber-physical manufacturing, artificial intelligence, measurement, additive manufacturing, industrial Internet of Things (IIoT), automation, robotics, and cyber-physical system (CPS) among others. This depicts that the concepts are closely linked in several scientific publications, considering that some of them are the key technologies in the fourth industrial revolution leveraged by M4.0. Moreover, metrology and industry 4.0 are closely linked, as indicated by the link strength of nine (9), which is higher compared to the rest of the link strengths in the cluster, which tells us that the technologies in Industry 4.0 are significant in transforming metrological practices in manufacturing industries.

Various concepts of development and trending are presented in Fig. 5. The trending shows that during the year 2019, concepts such as semiconductor manufacturing, additive manufacturing, quality management, interoperability, quality assurance, and coordinate metrology were the most researched. In the years between 2021 and 2022, machine vision, smart maintenance, predictive maintenance, artificial intelligence,

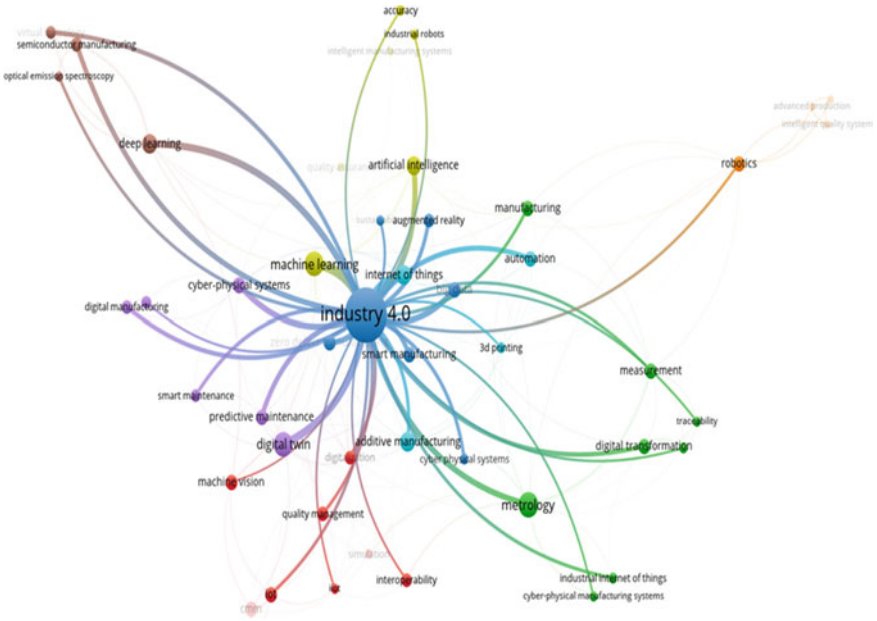

Fig. 3 Mapping of industry 4.0 cluster on VOSviewer. *Source* Created by the authors

and smart factories were the main concerns. This is probably because manufacturers experienced the challenges during COVID-19 and desire to reduce the dependence on human intelligence, replacing it with artificial intelligence, machine learning, smart factors and the like.

4.1.2 Co-authorship

The analysis entails general statistics of authors' contributions to multiple scientific publications. It indicates the frequencies and relatedness of authors in various publications regarding a particular concept. Considering the nascency of M4.0 concepts in the IR4.0 paradigm, the minimum number of documents by an author was set to be 2, giving a total of sixty-five (65) items for co-authorship analysis. A total of six (6) clusters represented by various colours were obtained, as indicated in Fig. 6. The clusters are marked by red, black, blue, yellow, magenta, and green, with the blue cluster being the most linked one compared to the others. The green, blue and magenta clusters are closely linked with their inter- and intra-linked items, indicating that authors in the clusters are closely related and cited in their scientific publications.

In the blue cluster, Brecher Christian, Xu Xun, Fey Marcel, and Beyse Ege are the co-writer in several publications, with Brecher Christian being the most co-writer, as indicated in Fig. 6. They specialised in production engineering computing, artificial

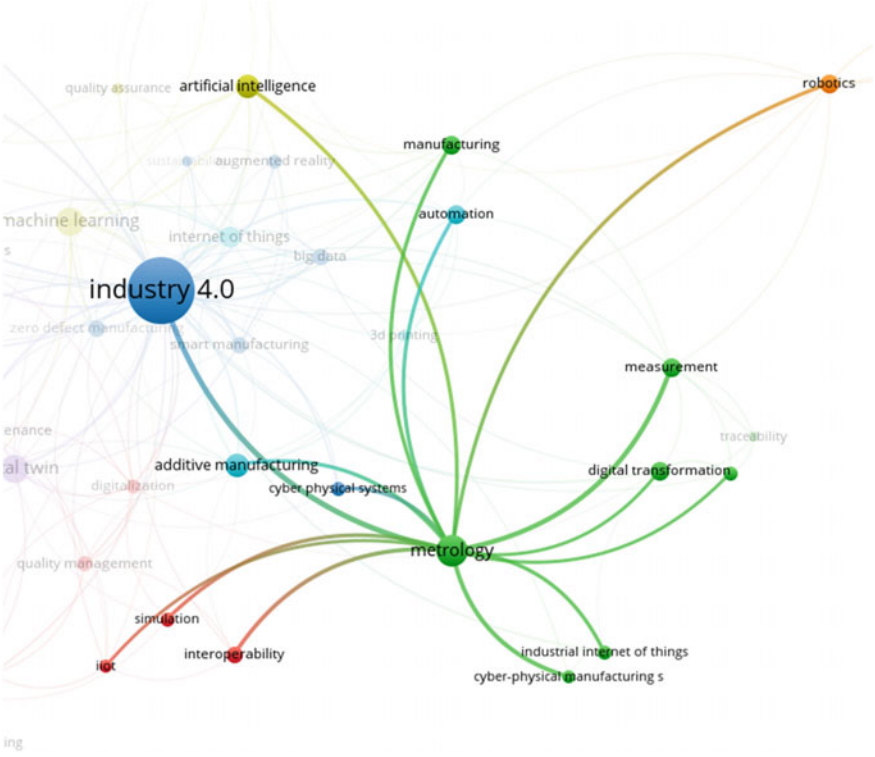

Fig. 4 Mapping of metrology cluster on VOSviewer. *Source* Created by the authors

intelligence, deep learning, quality cloud manufacturing, Industry 4.0, smart manufacturing control, manufacturing systems, advanced quality and process control. Among their field contributions are tough-based augmented reality marking techniques on production parts (Schmetz et al., 2022), dimensional metrology, Industry 4.0 and cloud manufacturing comparative analysis (Zhao et al., 2011).

In the yellow cluster, Robert Schmitt is the most co-writer with several publications in metrology, production engineering, quality management, cloud computing, and manufacturing systems. He was once a metrology and quality management chair at RWTH Aachen University. In one of his publications, he unveiled the significance of inline metrology as it enables measurement data to be obtained directly during production and used for faster and more effective process control and quality assurance (Schmitt & Moenning, 2006). The red cluster seems loosely connected to the rest of the clusters as it is only connected to the blue cluster with only a single link, which connects only two authors, such as Brecher Christian and Wegener Konrad. The two authors share their specialization in machine tools, and one of their publications was a review of state-of-the-art technologies to be adopted in the grinding process.

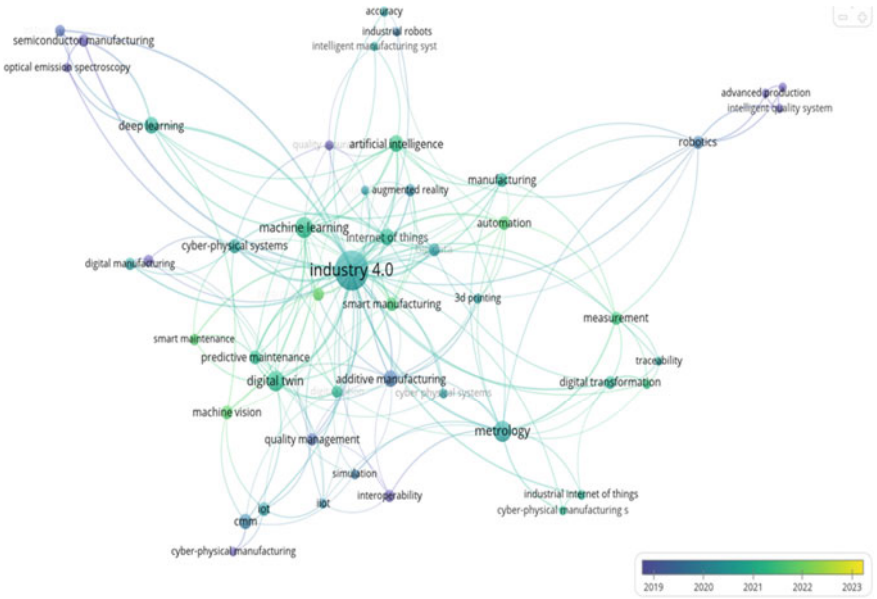

Fig. 5 Various concept development over time. *Source* Created by the authors

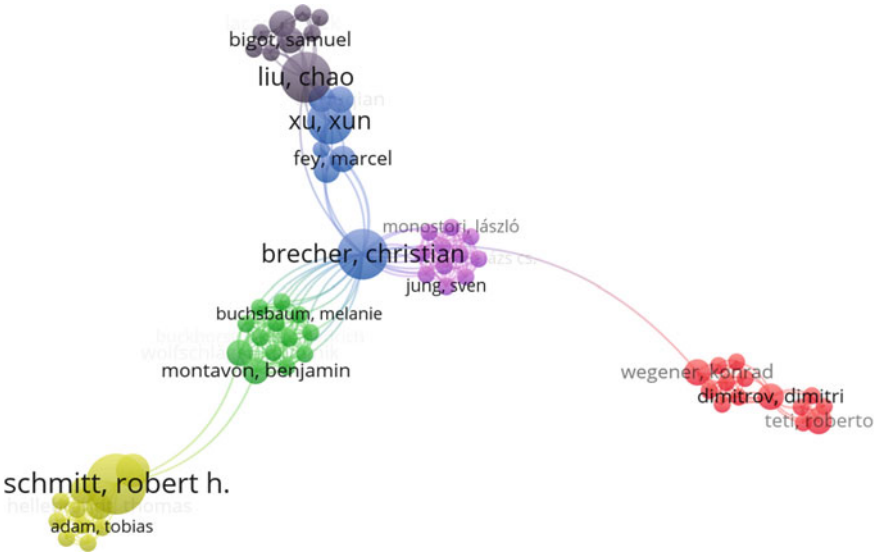

Fig. 6 Co-authorship network for authors' scientific publications. *Source* Created by the authors

4.2 Content Analysis

A systematic literature review was conducted to explore multiple factors that could enable manufacturing industries to adopt M4.0. It also unveils key technologies in the fourth industrial revolution that contribute to the digitalization of metrological services in the manufacturing industries, i.e., M4.0.

4.2.1 Metrology 4.0 and IR4.0 Interface

The disruptive nature of the IR4.0 technologies has impacted several industrial processes; metrology is one of them, wherein data acquisition in real-time, big data handling, and inline process control, among others, are mostly demanding (Alonso et al., 2019). Since IR4.0 is characterised by the digitalisation and integration into the cyber-physical systems, the digitalization of metrological services leveraging the IR4.0 technologies is thus referred to as Metrology 4.0 (M4.0) (Cunha & Santos, 2020; Gökalp et al., 2017). De Groot and Schmidt (2021) stated that there is a deep discussion on whether metrology developments drive industry 4.0 or industry 4.0 drives metrology developments. This is because both play a significant role in the enhancement of metrological activities in the case of M4.0 as well as in the advancement of industrial processes in the case of Industry 4.0.

In contrast to the previous industrial revolutions, metrology signifies its potential in IR4.0 across multiple units within the industry and other sectors of the economy in several ways. In smart manufacturing, data generation, analysis, and alteration are critical to avoid shut-off for inspecting the process. A 3D data capture of parts during production processes using a fast, non-contact optical metrology system is deployed to enable this (de Groot & Schmidt, 2021). Moreover, to enhance smart factories, metrology plays an important role in data collection and sharing through interconnected devices by implementing in-process metrology solutions (i.e., inspection) and non-contact 3D optical solutions rather than in-lab at the expense of time (Leslie, 2021).

Problems can be identified through in-process metrology before they arise and solution provision before they impact the entire production chain. In the calibration of measurement instruments used in industries, the IR4.0 technologies enable a touchless calibration of measuring instruments wherein there is no need to move the unit under test (UUT) to a reference standard that is remotely located. Implementing this will significantly reduce time spent, transport costs, and associated adversaries as it was before (Andonov & Cundeva-Blajer, 2018; Cunha & Santos, 2020).

Moreover, a noticeable development has been made by the Germany Institute of Metrology, commonly known as the Physikalisch-Technische Bundesanstalt (PTB). This is the national metrology institute providing scientific and technical services wherein the Digital Calibration Certificate (DCC) and its counterparts, i.e. Digital Certificate for Conformity Assessment (D-CoC), are already being developed to ensure uniformity in metrology (Eichstädt, 2020). Generally, M4.0 and IR4.0 depend

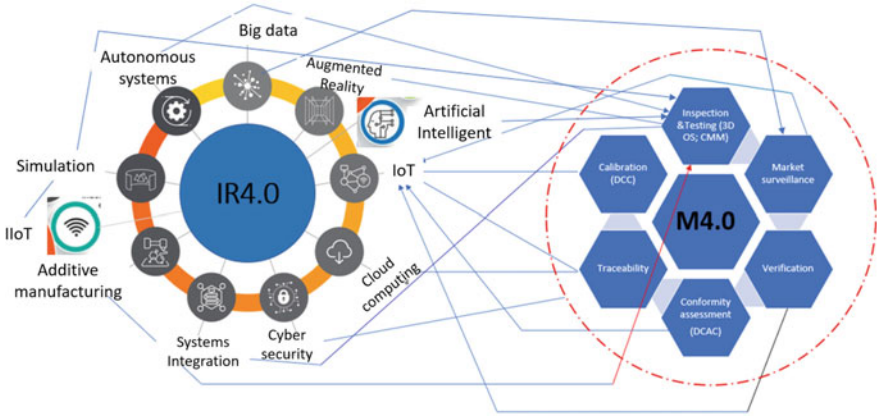

Fig. 7 Interface between M4.0 and IR4.0-related advanced technologies. *Source* Created by the authors

on each other in various aspects, especially in manufacturing. Figure 7 depicts the interface between M4.0 and IR4.0; in this figure, some advanced technologies adapted from IR4.0 aim to advance M4.0.

4.2.2 M4.0 Adoption Factors

Considering the interface between M4.0 and IR4.0 (Fig. 7), it is pointed out that adopting IR4.0 significantly influences the digitalisation of metrology services in the manufacturing industry. Therefore, the adoption factors for IR4.0 also depict the same for M4.0 since M4.0 is a subset of IR4.0. Several authors have presented multiple factors for adopting IR4.0 as it integrated the overall aspects of the industrial processes. At the same time, few articles have specifically referred to M4.0 adoption factors.

The concept of digitalisation of calibration services of measuring instruments was proposed by Cunha and Santos (2020). Cunha and Santos (2020) suggested that for the successful digitalisation of the process, some challenges need to be addressed, including creating new sensors to align with IR4.0, the availability of M4.0 professionals, and the security of data generated. Considering these challenges, the adoption factors to M4.0 can be deduced as the presence of a skilled workforce to enact the adoption of M4.0 as well as strategies to enhance data security.

Asghar et al.'s (2020) study regarding the challenges and roadmap for developing countries towards IR4.0 found that several factors should be considered for adopting IR4.0 technologies in developing countries. These factors include a supportive infrastructure in adopting the technologies, management commitment to investing in IR4.0 technologies, availability of a skilled workforce to enact the digitalisation of the entire process within the organisation, supportive organization culture towards changes in

the new technology domain, scalability, funding, and links between government and organizations resulting to the creation of favourable policies.

Asghar et al.'s (2020) study also stressed that infrastructure, such as reliable electricity, internet connectivity, and speed, plays a significant role in adopting M4.0 in the context of IR4.0. With reliable electricity and high-speed internet connectivity, the integration of smart devices such as sensors, measuring instruments, and robots in smart factories is enabled. The increased connectivity of devices within the smart factory necessitates the reliable security of data generated and shared in the devices; hence, the presence of scientific and technical manpower specialised in data science, big data analysts, and data engineers is significant to ensure the security of data and prevent any hacking that could severely destruct the entire network of connected devices (Xu et al., 2018).

A study conducted in Bangladesh by Islam et al. (2018) regarding the fourth industrial revolution in developing countries also identified several IR4.0 adoption factors where M4.0 is integral. Experts identified the factors through a semi-structured interview prepared by researchers. These factors include lack of government support, lack of knowledge, especially among key decision makers and planners, poor infrastructure, i.e. road, and internet connectivity, availability of cheap labour and high investment cost.

Infrastructure and education were also identified as the key success factors in adopting the technologies in the fourth industrial revolution by Rüßmann et al. (2015). The researcher stressed that technological infrastructure such as fixed and mobile broadband services are crucial to cater for the speed, security, and reliability of data and processes in manufacturing industries. They also suggested a country should adapt to a new curriculum and training to impart information technology skills and knowledge to workers and graduates from various levels.

A related study conducted by Maganga and Taifa (2023b) regarding quality 4.0 in the context of IR4.0 technologies found five crucial barriers to adopting Q4.0 in the manufacturing industries in Tanzania. These include reliable electricity, high-speed Internet, government support, a skilled workforce, and funding to cover the investment cost of the technologies. Other barriers to Q4.0 adoption include organization quality culture and cultural change, management support, awareness of Q4.0, vision, and strategies to align with IR4.0. These challenges represent the key factors that organisations should address to successfully embark on Q4.0, which is an integral part of M4.0 in the IR4.0 context. Table 1 summarises the various authors' adoption factors for M4.0, an integral part of IR4.0, as it leverages the fourth industrial revolution technologies.

In addition, Nhelekwa et al. (2022) found that currently, Tanzania's apparel manufacturing industries operate under IR3.0; thus, to be able to operate in the fourth industrial revolution, several factors should be taken into account such as a well-developed industrial infrastructure, the presence of engineering talent, stable commercial partnership, as well as market strategies aligning with IR4.0.

Kumar et al. (2021) also identified several challenges that impede organizations from adopting IR4.0 technologies that M4.0 leverages. These challenges, in turn, reflect several factors that should be considered for the successful adoption of IR4.0,

Table 1 Summary of M4.0 adoption factors

Source	Adoption factors
Cunha and Santos (2020)	Skilled workforce, strategies in data management
Asghar et al. (2020)	Management commitment, scalability, funding, infrastructure, organization culture, skilled workforce
Rüßmann et al. (2015)	Infrastructure, education
Islam et al. (2018)	High investment cost, infrastructure, knowledge, cheap labour, and government support
Maganga and Taifa (2023b)	Reliable electricity, high-speed Internet, government support, skilled workforce, and funding to cover the investment cost of the technologies, organization quality culture and cultural change, management support, awareness of Q4.0, vision, and strategies
Aggarwal et al. (2021)	Technology level, management commitment, economic issues
Nhelekwa et al. (2022)	Industrial infrastructure, market strategies, engineering talent, commercial partnerships
Kumar et al. (2021)	Value chain integration, cyber security, skilled workforce, funding, awareness, data management, data quality, standards and norms, and organization culture

within which M4.0 is an integral part. The factors include value chain integration, strategies for data security, skilled workforce, funding to cover initial investment cost, infrastructure to support IR4.0 technologies, awareness regarding IR4.0 technologies, data management, quality, company standards and norms, and supportive organization culture.

From the literature review regarding the adoption factors for M4.0 as an integral part of IR4.0, researchers repeatedly pointed out several factors in their studies. This indicates that the factors play a significant role in an organisation adopting M4.0 in an Industry 4.0 context. Therefore, in this study, seven factors must be considered critical for a manufacturing industry in developing countries to adopt M4.0. These are skilled workforce availability, adequate infrastructure such as reliable electricity, management commitment, awareness of IR4.0 technologies leveraged by M4.0, flexible organization culture, capital availability to cover the investment cost, and standards and norms to align with M4.0 implementation.

4.2.3 IR4.0 Technologies' Contribution to the Adoption of M4.0

The disruptive nature of the fourth industrial revolution technologies has impacted several sectors of the economy, including metrology. Various industrial processes in the developed countries utilized the potential of the IR4.0 technologies in mass

product customization, reducing production cost, decentralization, increasing efficiency, quarantine quality and productivity, etc. (Junaid et al., 2022; Syam et al., 2018). One process that utilises the technologies is measurement, called metrology 4.0 (Cunha & Santos, 2020). A systematic literature review has identified several applications of the fourth industrial revolution technologies in various metrological practices within the manufacturing industries and with notable contribution in the digitalization process.

Saif et al. (2022) developed a non-contact smart system based on interpreted STEP-NC for machine inspection (3SMVI) while inspecting holes' roundness. The inspection is enabled by using Internet of Things (IoT) architecture to facilitate communication between software and hardware components. The architecture comprises Filezilla, Raspberry Pi4, a Camera interface, and a lighting system. The system is an alternative to traditional techniques such as the contact measurement method (CMM), which is time-consuming, though its accuracy is higher. The Internet of Things (IoT) and Cloud technology were enablers in developing the Cyber-Physical Manufacturing Metrology Model (Majstorovic et al., 2017). The developed model enhanced the Control Measurement Machine (CMM) inspection plan in which the metrology product digital information was integrated using metrology features recognition. The system can identify and compensate for errors during measurement, leading to increased accuracy of the machine tools and quality product produced (Kvrgic et al., 2012).

Ullah et al. (2021) developed a computer vision-based measurement system to enhance the inspection of 3D mechanical parts for SME 4.0 in Pakistan. The system was integrated with the Internet of Things (IoT) technology to enhance real-time information sharing and transfer between system components, including hardware and software. Contracting to the previous traditional inspection approach, the system is low-cost, accurate, less time-consuming, and boosts production efficiency. An autonomous system like a robot is integrated with a laser radar-enabled inline measurement solution to inspect automotive dimensions. The technique has proven effective compared to off-line measurement systems such as CMM touch probes and laser scanners (Kiraci et al., 2020). The technique will enable automotive manufacturers to establish fast measurement procedures and proceed with feature-specific inline measurements without reducing measurement quality (Kiraci et al., 2020).

The application of virtual technologies in manufacturing industries enables the inspection to be conducted effectively and efficiently. This has been described by Ahmed et al. (2020) in their developed system for supporting inspection planning, referred to as the Smart Virtual Product Development System. The system stores information on past-designed products with similar features regarding product inspection planning. The information such as what is to be measured, the purpose of measurement and the available measurement instruments and devices are stored in the system and retrieved whenever a new design is incepted (Zhao et al., 2011). The development of a vision-based system was enabled by the application of machine learning technologies, i.e. machine vision and deep learning (Singh et al., 2023). The system is augmented by Convolutional Neural Networks (CNNs) capable of capturing images of processes and products within the manufacturing environment

for in-situ inspections rather than in an isolated area. It can also be implemented for dimensional metrology by utilizing the generated from a digitized image captured.

The transformation of manufacturing into smart manufacturing systems characterized by system integration and collaborative systems demanded a reliable measurement system (Rubel et al., 2022). The employment of the Internet of Things (IoT) and big data technology enabled the development of an in-process metrology system with automatic feedback to monitor processes in real time by integrating smart sensors and actuators in the production flow line. This system inspects product parameters in real-time as it passes through the measuring station. In case of any deviation in dimension and tolerance, it provides compensation to avoid part rejection and unnecessary reworking (Yandayan & Burdekin, 1997). The system is advantageous as it allows continued monitoring of product parameters, avoids repositioning errors during inspection, increases production rate, reduces time, and enhances the production of quality outputs (Atik & Ünlü, 2019; Rubel et al., 2022).

High surface roughness is one of the common challenges in additive manufacturing (Moroni et al., 2014). A post-processing additive manufacturing method is employed to reduce the surface roughness. During the post-processing, monitoring is imperative to ensure effectiveness during the process enabled by the in-process surface detection instruments. The instrument is designed by employing machine vision and machining learning technology of the fourth industrial revolution (Syam et al., 2018). To enable the in-process monitoring, the instrument is integrated with a post-processing machine to detect surface conditions and provide feedback to the machine for closed-loop control (Schmitt & Moenning, 2006). This system's employment has resulted in increased productivity and surface texture quality in polymer additive manufacturing.

The autonomous system also contributed to metrology 4.0 achievement, specifically inline inspection, where autonomous industrial robots are employed for mass customization production lines (Wu et al., 2020). A system utilises a 3D scanner to capture object's geometry and orientation data for inspection as the object approaches robot's working range while the installed camera performs a requested optical inspection. The system was proven cost-effective and accurately performed object tracking compared to high-speed cameras or laser trackers, which are expensive (Wu et al., 2020). Using virtual technologies such as virtual and augmented technologies, inspection and monitoring of the production process are enabled through virtual replicas of a real-world such as digital twin (DT). The replica is continuously updated with the data from its actual counterpart and environment as production continues bridging the virtual cyberspace with actual entities. During the inspection, the digital twin interacts with an integrated inspection system to inspect the products' parts based on the metric of their geometry complexity to reduce time and uncertainties during the inspection process (Gohari et al., 2019; Majstorovic et al., 2019).

Calibration of measuring instruments has always been done conventionally, which is time-consuming and prone to errors. With the help of IoT, cyber security, cloud computing and big data analytics, the digitalisation of calibration procedures enabled the need for transporting a unit under test (UUT) to a reference lab will no longer be

required. All the calibration procedures are conducted within a client's lab, where exchanges of data and pertinent information will be conducted via the Internet, and the digital certificate will be offered to the client (Andonov & Cundeva-Blajer, 2018; Cunha & Santos, 2020; Eichstädt, 2020).

5 Discussion

Generally, the fourth industrial revolution technologies are unevenly distributed in their contribution towards adopting metrology 4.0 in manufacturing. Some of the technologies are observed to be potentially enhancing M4.0 adoption, while the potentials of other technologies are not yet uncovered. Table 2 presents the nineteen (19) key notable contributions of the fourth industrial revolution technologies in multiple subject areas of M4.0 in the manufacturing industries out of fifty-six collected scientific publications.

5.1 IoT/IIoT, AI, and Big Data

Table 2 indicates the most frequent technologies applied in multiple metrological practices. The most frequent ones are big data analytics, Industrial Internet of Things (IIoT) and artificial intelligence, with eight occurrences for the first two and seven occurrences for the latter compared to the other technologies. Measurement processes, inspection and testing, and calibration, among other metrological practices, require a collection of large amounts of data from different sources interconnected using the Industrial Internet of Things (IIoT). These data must be reliable and accurate enough to produce accurate results. Hence, big data analytics is indispensable in ensuring that data are exploited and processed using artificial intelligence for their reliability and trustfulness. Moreover, the automation of various metrological processes such as automatic placement, measurement, inspection, testing, and sorting in industries relies on artificial intelligence/machine learning technology. Manufacturing 4.0 and IIoT also accelerate the industrial automation and inline metrology adoption in the manufacturing industries to ensure time reduction and quality of product produced while lowering production cost (Lazzari et al., 2017; Petri, 2020; Rambo & Sperling, 2021). Moreover, the automation of the inspection process is enabled by employing sensors and IoT devices to ensure no defective product is passed to the next production stage, aiming at zero defect output within a production section (Kubat, 2018). With the analysis of mass data made possible by the use of big data analytics technology, the prediction of defect are enabled during the production process to make sure defects are avoided before they occur (Küpper et al., 2019).

Table 2 IR4.0 technologies contributions in M4.0 adoption

Source	Article summary	Metrology 4.0 aspect	Industry 4.0 technologies									
			a	b	c	d	e	f	g	h	i	j
Hung et al. (2016)	Development of a novel cloud-based multi-tenant model creation service for automatic virtual metrology	Online monitoring			✓	✓						✓
Andonov and Cundeva-Blajer (2018)	Touchless Calibration concept for Industry 4.0 measurement equipment	Instrument calibration		✓		✓			✓			
Riaño and Alvares (2019)	Integrated Inspection System STEP-Compliant for the Exchange of Dimensional Metrology Data	Inspection		✓		✓					✓	
Gentner et al. (2021)	Making Virtual Metrology/Soft sensing with time series data scalable through Deep Learning	Process control		✓								✓
Junaid et al. (2022)	Creation of a high-precision measuring (metrology)-based system	Quality control		✓							✓	✓
Wieczorowski et al. (2023)	A novel approach to using artificial intelligence in coordinate metrology, including nanoscale	Coordinate metrology										✓
Maggipinto et al. (2018)	A Convolutional Autoencoder Approach for Feature Extraction in Virtual Metrology	Measurement										✓
Baur and Frazzon (2018)	Contribution of inline metrology to mitigate bullwhip effect in internal supply chains	Inline metrology					✓	✓				
Cunha and Santos (2020)	Digitalization of calibration procedure	Instrument calibration		✓		✓			✓			

(continued)

Table 2 (continued)

Source	Article summary	Metrology 4.0 aspect	Industry 4.0 technologies									
			a	b	c	d	e	f	g	h	i	j
Majstorovic et al. (2018)	Development of a framework for Cyber-Physical Manufacturing Metrology Model (CPM3)	Inspection		✓	✓	✓						
Sousa et al. (2022)	Integration of measuring devices in an IoT architecture	Quality control				✓					✓	
Majstorovic et al. (2019)	Error identification and compensation on Cyber- cyber-physical manufacturing Metrology Model (CPM3)	Inspection, Calibration				✓	✓					
Carmignato et al. (2020)	Dimensional artefacts to achieve metrological traceability in advanced manufacturing	Traceability						✓				
Gohari et al. (2019)	A Digital Twin for Integrated Inspection System in Digital Manufacturing	Inspection	✓	✓								
Schmetz et al. (2022)	Touch-based Augmented Reality Marking Techniques on Production Parts	Quality control	✓									
Saif et al. (2022)	Roundness Holes' Measurement for milled workpiece using machine vision inspection system based on IoT structure	Measurement			✓	✓						

(continued)

Table 2 (continued)

Source	Article summary	Metrology 4.0 aspect	Industry 4.0 technologies									
			a	b	c	d	e	f	g	h	i	j
Singh et al. (2023)	Vision-based system for automated image dataset labelling and dimension measurements on the shop floor	Measurement										✓
Sabbagh et al. (2022)	Organization of big metrology data within the Cyber-Physical Manufacturing Metrology Model (CPM3)	Hyper-spectral metrology		✓								
Maggipinto et al. (2019)	Deep Learning Approach for Virtual Metrology	Quality control										✓
Total appearance in various studies			2	8	3	8	2	2	2	0	3	7

Note a—augmented reality; b—big data; c—cloud computing; d—IoT/IIoT; e—autonomous systems; f—simulation; g—cyber security; h—additive manufacturing; i—system integration; j—artificial intelligence

5.2 AR, VR and Simulation

Both AR, VR and simulation appear to be less dominant in their contribution to M4.0 adoption, and it is probably because M4.0 is still in the nascence stage in contrast to other fields such as quality 4.0, supply chain 4.0, construction 4.0, etc., in the context of IR4.0. This does not mean they are not contributing, but their potential is yet to be exploited in elevating various metrological activities. For example, during inspection, a virtual replica or digital twin of a product can be used to conduct virtual inspection through a CPS domain where inspectors are enabled to interact with the product model or replica. During the interaction, an inspector can perform simulation, analyse, and foresee any defects that might occur during the production environment and optimize the process to avoid the defects. Moreover, simulation can also be used in the uncertainty of measurements to accurately determine the contribution of various factors to the measurement uncertainties.

5.3 Cyber Security, Autonomous System, and Cloud Computing

The digital calibration certificate (DCC), which is still in development by the German National Metrology Institute (PTB), promises to revolutionize the entire calibration process. With digital calibration, data and other instrument parameters will be stored in a metrology cloud in digital format. These data will be transferred and shared between client and calibration labs through a network that requires a security system to ensure reliability and accuracy. To enable this, an autonomous cyber security system can be developed to ensure data are secured from internal and external intruders that might corrupt the information stored and transferred via a network, as depicted in Fig. 8. The system could also be capable of synchronizing information between multiple users and alert users in case of any unusual event during the on and off calibration process in real-time.

6 Conclusion

6.1 Concluding Notes

The study entails a systematic literature review to figure out the contribution of the fourth industrial revolution technologies in adopting M4.0 in the manufacturing industries. Parallel to this, the interface between IR4.0 and M4.0 was also determined from the literature and factors for adopting M4.0. The bibliometric and literature content analysis revealed that both M4.0 and IR4.0 interdepend on one another, wherein the development of metrology, i.e., M4.0, accelerates the achievement of

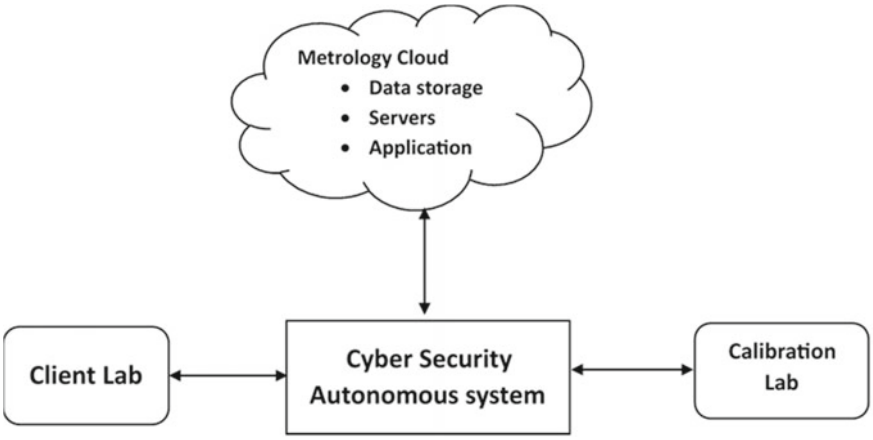

Fig. 8 Digital calibration of instruments enhanced by IR4.0 technologies. *Source* Created by the authors

IR4.0. For example, in smart manufacturing, all the processes are required to be automated, and the metrology process, i.e., inspection, is among them, so the deployment of inline inspection using a non-contact 3D optical solution enables inspection to be carried out in real-time without disrupting the manufacturing process hence smart manufacturing.

Moreover, various M4.0 critical adoption factors were identified, especially for developing countries, including skilled workforce requirement, management commitment, IR4.0 technologies awareness among employees, flexible organization culture to cope with the changes, capital for investment, as well as standards and norm development and adoption to comply with the international community. The study also found that not all the fourth industrial revolution technologies are employed in adopting M4.0. Some are employed more after realising their potential, while others are not yet exploited in the M4.0 domain. The review noted that big data analytics, IIoT, and AI are the top three technologies employed in various metrological processes. This indicates that the potential of other IR4.0 technologies in various metrological activities is not yet uncovered, considering that the M4.0 concept is still in the nascence stages.

6.2 Implication of the Study

Considering the available literature, the paper attempted to describe the significant contributions of IR4.0 technologies in adopting M4.0 in manufacturing industries and its adoption factors. It also unveils whether IR4.0 and M4.0 domains influence one another in their advancement. The study findings are significant

for researchers, industry practitioners and policymakers, with more emphasis on developing countries.

Researchers could further exploit the potential of other IR4.0 technologies in developing measurement systems that could foster modern metrological practices in various fields of science and business. The potential of IR4.0 technologies could benefit industry practitioners in adopting modern metrological practices in various industrial processes, including inspection, measurement and calibration, aiming at cost reduction, time-saving and productivity increase.

With the potential of IR4.0 technologies to advance metrological practices, policymakers could use the opportunities to define new strategies to ensure a smooth and supporting environment to foster the M4.0 adoption process within manufacturing industries. The findings reveal the huge contribution of Industry 4.0 technologies in adopting M4.0 in manufacturing industries. The metrology field involves quality aspects, including inspection, controlling, assurance and total quality management or quality improvement (Nzumile & Taifa, 2019, 2021; Taifa, 2016, 2022; Taifa et al., 2021a, 2021b, 2021c). The quality may be for any sector, including the textile and apparel ones (Taifa & Lushaju, 2020), quality improvement of long oil alkyd (LOA) resin (Gambi & Taifa, 2023; James & Taifa, 2022), thus involving metrological operations as well. Therefore, in adopting M4.0, quality aspects, such as the degree of excellence in transforming metrology-related operations for the manufacturing industries, should be further improved. Last but not least, the authors suggested that adopting state-of-the-art technologies in developing countries might not be effective unless the systematic roadmap or framework is well planned and employed to ensure a holistic view in the adoption process; hence, the study provides a basis to develop a transition framework.

6.3 Limitation and Future Work

The study was limited in several aspects during the stages of its accomplishment. The articles were extracted from Open Science, ScienceDirect, Google Scholar and Scopus, excluding other sources such as Web of Science, IEEE, etc., which could have added significant information regarding the topic. Only articles written in English were considered, excluding other articles which might have been productive in the study. Moreover, only engineering scientific publications were considered, excluding medical, social science and other fields that could have contributed significantly to the study, considering that M4.0 and IR4.0 affect multiple fields of study.

Moreover, from the study's findings, concentration has been put on the few technologies of IR4.0 when it comes to modernising metrological practices in the manufacturing industries. Technologies such as cyber security, autonomous systems, additive manufacturing, and cloud computing can potentially enable M4.0 adoption. For example, one of the challenges mentioned by Cunha and Santos (2020) in adopting M4.0 is the security of generated data during the calibration process; this cemented the need for further study on how to secure data during various metrological processes

to avoid cyber-attacks or hacking and ensure their reliability, especially in big data analysis.

Furthermore, a study on the smooth and holistic transition from the conventional metrological process, which is time-consuming, prone to errors and cost ineffective, should be done in the future. This could enable full adoption of M4.0, especially in developing countries where the level of technology is still very low compared to developed countries.

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Agile Human Resource Management: A Theoretical Contribution to a (R)evolutionary Approach for Managing People at Work

Alice Gomes Coelho, João Leite Ribeiro, and Regina Leite

Abstract The present chapter shows that Agile HR starts with the transition to an Agile mindset, but its definition is not consensual. Agile organizational cultures are described as transparent, based on open communication and are established on flexible multidisciplinary structures. The Agile organizational model requires employees and managers from different areas to collaborate regardless of their hierarchical position and business area. Organizations that adopt Agile HR seem to have better results in terms of customer satisfaction and organizational adaptability to adverse circumstances, but face resistance during process implementation. Agile HR involves a deep organizational transformation and rupture with traditional paradigms and habits and for this reason, it presents a challenge for HRM and professionals. HR undertakes the role of change agent and in collaboration with management ensures that the transformation and implementation of Agile HR is well understood by the members of the organization. Although organizations use different Agile practices and methodologies, they have a common purpose, which is to build a more competitive HR, and foster employee happiness and the sustainability of the business.

Keywords Agile management · Agile HR · Human resources management · Agile HR cases

1 Introduction

The global organizational context is going through a particularly challenging phase. The effects of the COVID-19 pandemic, recent technological developments (such as Artificial Intelligence systems), increasing digitalization and dematerialization of

A. G. Coelho · J. L. Ribeiro (✉) · R. Leite
School of Economics and Management, University of Minho, Braga, Portugal
e-mail: joser@eeg.uminho.pt

J. L. Ribeiro · R. Leite
Interdisciplinary Centre of Social Sciences (CICS.NOVA.UMinho), University of Minho, Braga, Portugal

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organizations, changes in global demographics and multiple factors of various kinds have led to continued change in organizations, transforming the concept of work and workers and the professions themselves (Dank & Hellström, 2021; Ribeiro & Gomes, 2016). The inevitability of adapting and re-adapting people and HRM makes it imperative that organizations act in a thoughtful, diligent and particularly Agile manner. Agile HR has been applied by managers and human resources professionals to guarantee the continuity and sustainability of organizations (Jafa et al., 2021).

Although Agile HR has elicited the interest of HR practitioners, it is a phenomenon that has not received much attention from HR researchers. Some scholars highlight this gap in the academic Human Resource Management literature (McMackin & Heffernan, 2021) and the need for studies in this field. The main evidence on the practice and effectiveness of Agile HR comes mainly from websites and articles and therefore the topic needs to be studied in greater depth to increase its levels of scientific credibility.

This chapter addresses the theoretical foundations of the Agile philosophy with the aim of analyzing, conceptualizing and problematizing the phenomenon of Agile HR from the perspective of various authors who have addressed this principle, policy and practice. The specific objectives are as follows: (1) Defining and presenting the main characteristics of Agile HR; (2) Describing the culture and organizational structure of Agile HR (3) Presenting Agile HR in an organizational context and describing its main determining factors (4) Describing methodologies, practices and indicators for implementing Agile HR in organizations.

The chapter begins with the Introduction and the following sections aim to conceptualize and problematize the concepts of Agile, Agile Mindset and Agile HR, present the role of the HR professional and the Agile HR worker, describe the organizational architecture of Agile organizations and the operationalization of Agile HR and finally distinguish Agile methodologies, methods and tools. Three case studies of organizations that have implemented Agile HR are also presented.

2 From Agile to Agile HR

2.1 Origins and Conceptualization of Agile

Agile has its origins in technological organizations, particularly software development (Medinilla, 2012). According to Jafa et al. (2021), the basis of Agile is the definition of what to do and what not to do in software development. The goal of Agile is to maximize the customer value by reaching the highest level in terms of excellence and effectiveness (Doz & Kosonen, 2007). Shore and Warden (2008) reveal that Agile development is not a specific process to follow. The authors argue that teams do not practice the Agile method because Agile development is a philosophy.

In 2001, the first steps towards advocating Agile began with the creation of the Agile Manifesto, a key milestone in defining its values and principles (Beck et al.,

2001). This document serves as the basis for implementing Agile in organizations. The concept of Agile is sometimes used synonymously with flexibility because both agility and flexibility imply adaptability at their core (Nawneet, 2021). However, Nawneet (2021) explains that acting with flexibly implies reactive adaptation to events, while acting with agility implies proactive action, which precedes events.

Agility means the ability to exploit or create for one's own benefit by changing the patterns of resource development in a careful, purposeful and simultaneously Agile way, setting aside traditional approaches that adopt predefined, stable plans and pre-existing business models (Doz & Kosonen, 2007). The need for attention to detail and agility presents a contradiction and is a source of management conflict (Doz, 2020). Agility and innovation are a prerequisite for the long-term growth and success of an organization operating in an increasingly volatile, uncertain, complex and ambiguous environment (Yijun et al., 2020). "Organizational agility is a strategy to stay adaptive and excel in competition in a fast-changing market environment" (Junita, 2021, p. 1). It also "helps organizations improve product variety with minimal environmental impact and thus increase cost-effectiveness" (Bouguerra et al., 2021, p. 2).

The concept of Agile organizations is used to characterize a type of organization capable of adapting easily to fast-changing and highly unpredictable contexts and environments. The Agile organization is seen as a fundamental condition for creating a work environment with satisfied, involved and creative workers who can add value to the organization and its customers (Junita, 2021). Joshbersin (2019) states that Agile is a philosophy, a culture and a set of management practices. Thus, Agile management is an innovative way of organizing and reorganizing traditional work to increase effectiveness in the way of working (Nawneet, 2021).

The concept of Agile is no longer solely used in the field of technology and technological organizations and is now being applied to other areas and functions (Cappelli et al., 2018), such as human resources. The COVID-19 pandemic has highlighted the importance of adaptability and objectivity of businesses, and raised the awareness of the needs of different businesses. According to Dank and Hellström (2021), organizations need to understand what is happening to with customers, and at the same time promote the safety and well-being of workers. In many organizations, the workplace has changed from a physical space to a digital space, making it urgent to recognize the role of technology in automating work and the need to improve the employee experience (Huzooree & Ramdoo, 2015).

2.2 Agile Mindset

The Agile philosophy is built on the Agile Manifesto, which is a response to the challenges faced by the traditional software development process (Ebert & Paasivaara, 2017). In the words of McMackin and Heffernan (2021): "The Agile concept operates at multiple levels—from philosophy to culture and mindset, through to processes and methodologies, and affecting roles, behaviors of leaders, teams and individual

employees" (p. 3). The Agile mindset is based on transparency and aims to achieve agility rather than acting in an Agile way (Mordi & Schoop, 2020). The transition to Agile HR requires a change of mindset and one of the critical success factors is the human factor (Nawneet, 2021). In this sense, Khan and Madhavapeddy (2016) indicate that the first stage of the Agile transformation is to hire the right person who knows how to develop the Agile mindset.

Mordi and Schoop (2020) state that the main characteristics of the Agile mindset are responsibility, trust, openness, a sense of ownership, continuous improvement and a willingness to learn and grow continuously. Valuing the customer's opinion and co-creation are two core values of the Agile mindset. In the same vein, Denning (2018) reveals that the Agile mindset is customer-centric and involves collaboration and trust in employees. Nawneet (2021) argues that Agile HR is a way of thinking and recognizing that everything HR does prioritizes and is focused on the value provided to the customer.

The Agile Mindset "is underpinned by specific personal attributes on the individual level and an enable environment on the organizational level, which allows for autonomy of people and teams, managing uncertainty and a focus on customer value" (Mordi & Schoop, 2020, p. 9). The transition to Agile HR necessarily implies leadership oriented towards cultural management (Jafa et al., 2021). The organization has to develop a positive atmosphere, which includes shared beliefs and goals that translate into workers placing value in their work and a revolution for the customer (Nawneet, 2021). For the organization to have valuable internal resources and be considered competitive Junita (2021) urges some management actions, namely the adoption of an intellectual agenda (shared mindset), a behavioral agenda (cultural identity translated into work behavior) and an agenda process (consolidation of culture based on management practices) (Junita, 2021). To sum up, agility requires a culture of empowerment where workers have the authority and autonomy to respond to customer needs. HRM can help create this culture (Ulrich & Yeung, 2019), and therefore it is important to conceptualize Agile HR.

3 Agile HR: Conceptualization and Purpose

Agile HR refers to the application of Agile in HRM with the aim of adopting agile ways of working (Rigby et al., 2020), which implies both teamwork and workers performing their tasks in a self-directed and future-oriented way (Grass et al., 2020). Denning (2018) defines Agile HR as a global movement that is transforming the world of work and the way organizations manage human resources (Cappelli et al., 2018). Cappelli et al. (2018) present the concept of Agile HR as Agile lite, in which organizations apply the general principles of Agile without using all the tools and protocols of technology. It refers to a simplified, less rigid and more adaptable approach of Agile principles and methodology. The concept of Agile HR is therefore explained from the perspective of human resources practices. Huzooree and Ramdoo (2015) point out that the transition to Agile approaches involves both abandoning and

unlearning traditional habits and acquiring new ones. In this regard, reviewing traditional human resources techniques and practices is a priority for HRM (Huzooree & Ramdoo, 2015). There is a need to reflect on the HR value proposition and renew talent management centered on the employee experience and "looking for the sweet spot where talent management practices are good for the worker and the employer" (Claus, 2019, p. 210).

The HR Agile Manifesto, like the Agile Manifesto, was created with the aim of consolidating the guiding principles and values of Agile HR, and has been signed by more than four hundred people and translated into eleven languages (Almagro et al., 2017). Almagro et al. (2017) present the pillars of Agile HR as follows: collaborative networking, transparency, flexibility, commitment, intrinsic motivation and ambition. The critical factors for Agile HR success are: Agile Mindset, co-creation, human-centered and evidence-based leadership (Nawneet, 2021). In this sense, Khan and Madhavapeddy (2016) argue that the four values of Agile HR development are adaptability, transparency, simplicity and unity. Agile principles are mirrored in the operationalization of human resources, in the structures, functions, processes and tools, skills and behaviors of the management and workers of Agile organizations (McMackin & Heffernan, 2021).

Agile HR facilitates the emergence of creative talent, creates potential and makes organizations profitable (Averineni & Swathi, 2019). HRM plays a crucial role in helping organizations improve their agility. In organizations where the central aspects are speed, adaptability and execution, HRM is a prerequisite for achieving sustainable competitiveness (Saha et al., 2017).

Agile HRM is deemed a strategic process, where the central element is people, based on results, which is different from the process-focused approach (Jafa et al., 2021). There are two different ways of looking at Agile HR: HR for Agile and Agile for HR. HR for Agile refers to the design and implementation of HR systems to support Agile implementation in the organization and Agile for HR corresponds to the application of Agile principles in performing the HR function (Darino et al., 2019).

3.1 Agile for HR: The Role of HR Professional

In 2015, Bersin wrote that "the human resources profession is at a crossroads as the global economy grows and technology has made organizations highly interconnected and transparent, what HR does has to change" (p. 5). According to Biron et al. (2021), COVID-19 is an example of the need for disruptive change and rapid adjustment on the part of the HR function. The COVID-19 pandemic has forced many organizations to readapt to the new circumstances, such as the implementation of remote working, since many processes changed to online format. The Agile approach presents the most effective solution for overcoming the challenges of rapid transformation at work and in the workplaces (Jafa et al., 2021).

In a practical context, Agile HR means the ability of the HR function "to give immediate response in time towards the changing scenario of workplace problems, business needs and employee expectations" (Averineni & Swathi, 2019, p. 2332). Agile for HR is a way of organizing work and the HR function that facilitates responsiveness and adaptability to work activities, structures and fluctuations (HR Trend Institute, 2019). Moreover, Agile for HR means embracing the mindset and positioning the human being first, therefore centering processes on the internal customer (Jafa et al., 2021, 38) and analyzing how HR can apply the Agile mindset and various working methods within teams and projects (Agile HR Community, 2019).

The human factor emerges as a facilitator, a driving force for the transformation of an Agile organization because the dynamic dimension of agility (Junita, 2021) and its adaptation to the mindset are basic requisites that prompts the successful implementation of Agile. The human resource professional plays a crucial role in the implementation and operationalization of Agile HR due to his/her contribution to the creation of "an open work space where people can freely communicate to enhance this collaboration" (Khan & Madhavapeddy, 2016, p. 49). The company's strategy is executed through the HR function and the Agile HR system in order to shape employee's behaviour and allow organizations to adapt to the dynamic environment (Junita, 2021). One of the tasks of HR professionals during the Agile transition is to design a structure for the new roles and responsibilities, taking into account the doubts and problems raised by employees.

Agile HR systems include policies and practices for people management, work design, performance management, capacity building, training and career development, reward systems and organizational communication (Junita, 2021). Human Resources professionals seek to develop specialists, make them closer to the business where they add more value (Bersin, 2015), and foster an environment where workers feel motivated and productive (Moreira, 2017). However, one of the difficulties HR managers face is prioritizing HR resources in order to achieve the highest results (Jafa et al., 2021). That said, the HR professional assumes a role that is not only operational, but also strategic, which necessarily affects organizational performance.

According to Jafa et al. (2021), HR professionals can play different roles in the organization but their contribution is an essential requirement in the Agile transition. Khan and Madhavapeddy (2016) suggest a set of new rules and roles for HR as a result of the transition from traditional to Agile management. In traditional management, the focus is on alignment and control, which leads to order, execution and control (Khan & Madhavapeddy, 2016). In this regard, the HR professional job is to exert control and implement standardized procedures and systems to ensure execution and alignment (Kaufman, 2014). In Agile Management the focus is on the customer and the speed of delivery which triggers adaptability and innovation. The role of HRM and HRM professionals is to promote collaboration and decision-making through strategies, programs and systems. Given the evidence, there is a need to work on a more flexible organizational structure and focus on more horizontal and networked functional relationships, giving workers greater control over their work, autonomy and responsibility (Claus, 2019).

In the Agile perspective, workers are considered an asset rather than a cost to the organization and the role of the HR professional is to organize people so that they can carry out their activities (Khan & Madhavapeddy, 2016). Looking at the worker in this way embodies a contemporary view of HRM (Khan & Madhavapeddy, 2016) that corresponds to the Harvard Model of HRM, which emphasizes the importance of human relations in people management (Storey, 1989). The so-called soft approach seeks to obtain the desired behavior from employees through HRM principles, policies and practices focused on humanistic and participative concerns as well as win–win relationships that foster a sense of cooperation and responsibility among employees, ensuring the success of the organization, which is similar to the Agile Approach (Kaufman, 2014). In the same vein, Jafa et al. (2021) concluded that the most suitable HRM model for Agile management is that of the Harvard School because it takes into account "the need for adding flexibility to deal with the strategic ambiguity and uncertainty, this is proposed to be done and enhanced it by Agile concepts and methods" (p. 43).

3.2 Agile HR: The Role of the Worker's Experience

Itam and Ghosh (2020) assert that organizations that adopt Agile HR practices tend to reflect on how workers experience the work environment. The employee experience is the sum of all the interactions that take place between employees and the organization (Morgan, 2017). It is the result of the meaning, impact and appreciation attributed by workers to their jobs and the interaction between the organization's values and environment, co-workers, management and customers, the job performed and the tools, and physical environment (Rasca, 2018). In operational terms, Yohn (2016) states that the construction of the employee experience can begin with the segmentation of employees into clusters, bearing in mind their opinions, interests and needs. Morgan draws the attention to the fact that employee engagement and employee experience are distinct terms and have different meanings. Worker commitment refers to short-term changes made by organizations to improve the way they work. Worker experience presupposes long-term changes, solutions that are human, flexible, adaptable and valued by the worker, in short, a worker-centered process (Morgan, 2017).

The concept of employee experience tends to recur when studying Agile organizations. It is important to note that for agile organizations, the employee represents the "heart" of the organization—the employee is a customer, and should be treated as such (Dank & Hellström, 2021; Morgan, 2017). Therefore, to ensure the development of a solid customer experience, it is important to consider internal customers as valuable resources (Itam & Ghosh, 2020). The employee experience, from an organizational point of view, is what the organization projects and has created for its employees. From the employees' perspective, the experience is synonymous with their reality and what they prefer to work with, which gives the employee experience a subjective nature since each employee has his/her own characteristics and different

emotions, perceptions and behaviours that vary based on their experiences and interpretations (Itam & Ghosh, 2020). Yohn (2016) states that in order for the employee experience to be plausible, it is necessary to apply customer experience strategies to the employee experience.

Shifting to an Agile organization is a challenging process, as it requires workers to change the way they think, work and interact (Koutsikouri et al., 2020). In this sense, workers also have to adapt to this new way of working. These changes trigger new experiences in workers that have to make sense of the change and gradually adjust to the way they work and the functioning of the team (Koutsikouri et al., 2020). Kaufman (2014) explains that people are less resistant to change when they play a role in its development. Therefore, it is necessary to involve workers in change processes, and consequently in creating their experiences (Ribeiro & Gomes, 2016). This view of the employee as a competitive advantage is in line with the resource-based theory, which emphasizes that an organization's value comes from its tangible and intangible resources and capabilities (Holbeche, 2015).

3.3 Organizational Architecture and Implementation of Agile HR

The way work is structured in Agile organizations leads to changes in organizational design to accompany the transition to Agile HR. Claus (2019) asserts that work has changed from a process management structure (i.e. a set of routine tasks) to a project management structure (i.e. initiatives that have a beginning and an end). Traditional HR is focused on individuals while Agile HR puts the team at the center (Cappelli et al., 2018). Cappelli et al. (2018) point out that teams with a need to organize themselves "project by project" are associated with Agile HR systems and tend to focus more on accomplishing team goals rather than individual goals. Agile organizations are anchored to structures based on flexibility, horizontality, collaboration and employee experience (Dank & Hellström, 2021). Dank and Hellström (2021) suggest a progressive path that leads to a customer-centric model for operating a network Agile HR, adjusted to the organizational reality of each organization. This model is characterized by low hierarchical dependence and high structural flexibility. Employees have flexible roles and reporting lines, which vary according to the project. Thus, the structure of the teams varies according to the client's needs and the skills required by the projects. Given this organizational architecture, the role of agile HR is to help the organization adapt to the uncertain (McMackin & Heffernan, 2021) and focus on the employee experience (Narayanan & Ferreira, 2019).

The Agile organizational architecture is described as "personalized, simple, authentic, responsive and transparent" (Claus, 2019, p. 210). In practical terms, the Agile structure distributes human resources into different groups, which are characterized as small, functional, independent and from different sectors or departments. Each team member possesses different skills, which are recognized and put at the

service of the company, allowing each group to accomplish what is expected by maximizing the skills and value of each member (Bossert et al., 2018). Bossert et al. (2018) note that this distribution makes it possible to deliver a large number of projects of great value to the client with fewer human resources. This highlights agility as a crucial factor in determining an organization's performance (Škare & Soriano, 2021). In the case of Human Resources, the functions are segmented into multidisciplinary teams that are empowered and continuously aligned with organizational needs through open communication during the short operational cycles of the team's activities (McMackin & Heffernan, 2021).

The operationalization of Agile HR foresees collaboration and communication between human resources from different teams in order to provide employees with a positive experience (Narayanan & Ferreira, 2019), breaking down barriers between human resources team members, managers and employees, to promote greater communication and transparency by adopting a simpler and more Agile approach (Narayanan & Ferreira, 2019). Agile HR operating models favor and demand the transformation of HR teams and the employee experience, while meeting the needs of the business. Thus, Agile HR involves overcoming HR silos and inviting managers and workers as well as customers to collaborate in getting the job done (Ulrich & Yeung, 2019). Human Resources practices are service-oriented, data-driven and networked and therefore influence the functioning of Human Resources teams and leadership (Narayanan & Ferreira, 2019). Agile operating models "allow for quick and efficient reconfigurations of strategy, structure, processes, people and technology toward value-creating and -protecting opportunities" (Darino et al., 2019, p. 2).

In a dynamic and fast-changing environment, the HR function can add value to stakeholders, including end users, managers and employees based on the philosophy and principles that underpin the Agile way of working (McMackin & Heffernan, 2021). It is necessary to involve all parties, especially in areas where there is greater resistance to change (Jafa et al., 2021). The Agile approach emphasizes pace, which can present a risk when fully applied to HR programs (Jafa et al., 2021). In this regard, the operationalization of Agile HR may not follow all the procedures and the same pace as the Agile approach, because Agile comes from a different discipline—software development. Morgan (2018, p. 20) suggests a model of eleven epics[1] that can be applied to organizations of various teams and sizes in the Agile transformation process, which includes: "(1) Define the why; (2) Prepare a sponsor; (3) Determine organizational readiness; (4) Specify the objectives; (5) Foster two-way communications; (6) Build broad sponsorship; (7) Create a change team; (8) Choose an Agile system; (9) Prepare stakeholders and teams; (10) Go "All-In" and (11) Customize through experimentation" Morgan (2018, pp. 20, 21).

[1] High-level business story or them from which all use case and user stories are developed (Goodpasture, 2016, p. 344).

4 Agile Methodologies, Methods and Tools: Practical Examples

4.1 Definition of Agile Methodology and Method

The methodology consists of the activity to produce a certain result with specific methods, or practices for each identified activity. Goodpasture (2016) defines methodology as the life cycle of the project. Agile methodologies and practices are situational, decentralized and "self-managed, with an emphasis on near-continuous responsiveness to customer need" with a focus "on the quality of the result, even if the result is not very predictable at the outset and not according to plan" (Goodpasture, 2016, p. 30). Shore and Warden (2008) define method, or process, as a way of working. Some processes "are written, as when assembling a piece of furniture; others are ad hoc and informal, as when I clean my house" (Shore & Warden, 2008, p. 9).

Agile HR project planning relies on the use of Agile and user-oriented methods such as prototyping, task-centered sprints, interactive feedback and team decisions (Cappelli et al., 2018). McMackin and Heffernan (2021) point out that the use of individual Agile tools and techniques can be observed in many organizations, but the isolated use of those tools is considered a limited form of Agile adoption. Shore and Warden (2008) assert that "Agile methods are processes that support the Agile philosophy" (p. 9). Therefore, copying these methods and tools does not make an organization Agile. It is important to conceptualize and understand the practical application of these concepts.

4.2 Agile Methods: Scrum*,* Kanban *and Prototyping*

The most popular methods in the Agile approach are *Scrum* and *Kanban*. The term *Scrum* was introduced by Takeuchi and Nonaka (1986), who presented the successful development of seven hardware products using iterative methods (Takeuchi & Nonaka, 1986). *Scrum* is often referred to as a methodology, however SCRUM.org clarifies that Scrum is a scientific method of empiricism, a form of management. The *Scrum* method implies a break with traditional project management paradigms and is related to work organization, client involvement and delivering quality to all project beneficiaries and users (Goodpasture, 2016). *Scrum* consists of a management structure in which various practices can be allocated (Goodpasture, 2016). By way of example, *Scrum* can be used as an operational model, adopting the *Scrum* method as a way of working.

Kanban is a Japanese management method created by Taiichi Ohno and applied in the Toyota factory (1953 cit in Bürki, 2019). This Agile method aims to achieve faster response times (Bürki, 2019) and consists of a set of several sequential steps and processes (Goodpasture, 2016). The workflow is visualized by means of a *Kanban*

board, through which it is possible to keep track of the different tasks in the project (Bürki, 2019). David Anderson applied this concept to IT and made it more efficient (2007 cit in Bürki, 2019). As an example, at Sky Group the HR team uses a *Kanban* board with the aim of visualizing, prioritizing and managing the daily workflow, maintaining control between sprints (Agile HR Community, 2019).

Prototyping is a method used in Agile HR. Otto and Wood (2003) describe a prototype as an artifact that approximates one or more features of a product, system or service. Prototyping applies to the design process of HR projects. When ideas come up to carry out an HR project, prototypes can be built and tested by users to gather their feedback. Through these experiments, it is possible to learn what is repeated and what is not repeated in the projects. Each moment of prototyping requires a strategy that is adopted to solve the problem or design opportunity identified. Thus, the strategy chosen influences the nature of the information that can be learned and known through the prototype (Gero, 1990). Applied to performance management, this would involve, for example, designing a performance management system together with users, called a prototype, which would then be tested by users and corrected using the feedback collected.

4.3 Agile Tools: Sprint *and* Feedback

Sprint is an Agile tool can be defined as a certain period of time during which the team works on a fixed number of tasks that are assigned to the *sprint* (Goodpasture, 2016, p. 325). It has a specific duration, usually weeks, with requirements planned at the beginning of the *sprint* by an empowered team (McMackin & Heffernan, 2021). Darino et al. (2019, p. 3) state that working in *sprints* "creates a cadence into which collective and individual feedback naturally fits". McMackin and Heffernan (2021) explain that Agile projects are usually divided into *sprints*, which "emphasize the rapid delivery of elements of a solution that can be tested in collaboration with customer(s)" (p. 3). Let's take the example of an organization that wants to recruit a production engineer and chooses to work in *sprints*. To carry out the "Recruitment and Selection of a production engineer" project, the organization starts by segmenting the tasks (i.e. publishing the advertisement, screening CVs, carrying out interviews) and defines the time it will take to complete the project (i.e. one month). The project is divided into two *sprints* and there would be weekly feedback meetings and meetings at the beginning and end of each *sprint* to define or gather requirements and to evaluate the project's progress. The first *sprint* lasts two weeks and two tasks are set to be completed (i.e. publishing the advertisement and screening of the candidates' CVs). The tasks are distributed among the team strategically. The second *sprint* lasts two weeks and the remaining tasks are allocated until the new employee is selected.

A culture of feedback must be imminently present in an Agile Organization (Trost, 2017). Peer feedback is a multidirectional, usually informal process that is given horizontally and regardless of hierarchical position (Cappelli et al., 2018; Holbeche, 2015). Agile organizations are characterized by a culture of greater autonomy, which

is able to take risks, and open up opportunities for employees to expand and take on more responsibility, discovering how they can improve themselves (Darino et al., 2019). In successful agile organizations, the focus is on team performance, goal setting and performance evaluation, often allowing teams to set their own goals to drive ownership (McMackin & Heffernan, 2021). One example of the application of feedback is in performance management. In an Agile organization, annual performance feedback is not adjusted because workers carry out short-term projects that can be managed by different leaders and teams (Cappelli et al., 2018). In this type of organization, performance tends to be monitored on a project-by-project basis (Cappelli et al., 2018), and in a structure of "empowered and autonomous teams" it makes sense to manage talent at a group level by introducing team objectives (Darino et al., 2019, p. 3). In short, the following performance management practices can be observed in Agile organizations: continuous and multidirectional feedback, different performance and project cycles, simplifying the evaluation process with frequent follow-up meetings and creating common performance goals. In an organizational context, the adoption of feedback, working in *sprints* and collaborative work can mean redesigning the performance management process.

In view of the above, it is important to present cases of organizations that demonstrate the use of Agile HR in a practical context. This is the focus of the following section.

5 Agile HR in Practice

This section aims to demonstrate the applicability of Agile HR by presenting three case studies of organizations working with Agile HR, based on the studies "HR Goes Agile" and "HR goes Agile: a case study in BBVA" (Forcano, 2018). The representatives of the IBM, ING and BBVA highlight a number of motivating factors that have led to the adoption of Agile HR in these organizations. The head of HR at the BBVA Group said that the pace of HR execution was not aligned with the organization's strategic vision, and therefore there was a need to become more agile in terms of response times (Forcano, 2018). The IBM Group was going through a period of transition that required agility. The ING Group saw a high number of digital interactions with customers via mobile applications and this factor highlighted the need for a more agile HR in order to respond to customer needs (Forcano, 2018).

The BBVA and ING Groups are organizations in the banking sector and have similarities in the Agile transformation process. The BBVA Group began the Agile transformation process in 2017 with the creation of multidisciplinary *SCRUM* teams in Spain, Mexico and South America (Forcano, 2018). The ING Group started the Agile transformation with the creation of thirteen multidisciplinary teams of one hundred and fifty members each, aimed at addressing specific domains. Each team is responsible for ensuring the proper execution of their projects from start to finish, and so workers "are encouraged to solve problems on the ground rather than pass

them on someone else…" (Barton et al., 2018, p. 17) which gives a sense of ownership to each project and implies a greater connection with the customer. Forcano (2018) adds that the changes made to the organizational structure have led to a new administrative model that has required the assignment of new roles, responsibilities and new communication tools to increase transparency. In operational terms, these teams work in two- to three-week cycles to test, iterate and thus build new solutions based on customer feedback.

At the IBM Group, the employee experience has become the core of the organization, which has required a change in mentality. Cappelli et al. (2018) point out that they used to rely on specialists to build HRM programs, but nowadays HR professionals and workers from other sectors develop projects in joint collaboration. For example, HR professionals ask employees for feedback on their onboarding process. Cappelli et al. (2018) argue that this practice promotes employee involvement and the improvement of the welcoming and integration processes. Worker experience teams have been set up in the BBVA group, highlighting the importance of considering the needs of workers in an agile organization. In this sense, Forcano (2018) states that Agile is a path without end, as the ultimate goal is to promote a cultural transformation that puts workers at the heart of the organization.

6 Recommendations for HR Managers and Professionals

Firstly, it is worth mentioning that strictly applying the methods and practices of Agile development to human resources entails a risk, as mentioned by Jafa et al. (2021). Agile HR requires a high level of knowledge about the organization's internal resources to ensure that they are used to best effect. As mentioned above, the Agile practices and tools to be used depend on the organization, which is in line with the concept of Agile lite presented by Cappelli et al. (2018), who indicate that Agile HR applies the general principles of Agile without using all the technology tools and protocols. Agile can begin with the process of abandoning unnecessary procedures, and use planning to simplify and act more strategically. In this sense, Huzooree and Ramdoo (2015) argue that the Agile approach involves learning new habits. Thus, thinking about how to make processes less bureaucratic in order to respond more quickly to the customer can be a relevant practice, as it is not necessary to buy software in order to be Agile.

Restructuring processes are essential so that decisions don't clash in hierarchies, which is why the organization needs to remain horizontal so that changes can be easily implemented. In this vein, the way to develop Agile HR in a pyramidal or bureaucratic structure is to make it as horizontal as possible. In the case of a traditional organization, the process of implementing Agile HR can start with a less bureaucratic department and use this successful story as an example for other departments. However, abandoning bureaucracy is not synonymous with disorganization. In Agile HR, HR processes and practices need clarity and documentation because the more transparent and documented the communication, the less need there is for hierarchy.

In Agile HR, the key aspect is results. To achieve the result, teams are developed according to the project and the criteria for adding value to each element/human resource. Each employee can participate in several projects and teams at the same time (e.g. R&S project, performance evaluation). Projects go through a team planning stage, in which project members become aware of their involvement and when their feedback will be requested. Furthermore, the greater the impact of the decision, the more human resources management must be involved and participate in making the decision. The main focus of Agile HR is the customer, not only or external customers but also employees and managers as internal customers. The customer has to be involved in HR projects and company decisions, as this is the only way to achieve a final product able to attend the customer's needs.

7 Conclusion

Today's organizations are going through a number of structural and mindset changes due to the need to adapt to the business environment. Agile is a solution that emerges from the Agile Manifesto and is at the forefront in times of change and disruption. The COVID-19 pandemic has highlighted the importance of Agile as organizations have experienced the need to reinvent and adapt (e.g. moving from face-to-face to remote formats) (Dank & Hellström, 2021; Huzooree & Ramdoo, 2015).

Before starting to implement Agile, organizations need to think Agile (Mordi & Schoop, 2020). The application of Agile in HRM also has the Agile Manifesto at its core. HR professionals apply Agile HR in organizations through their structures, design and implementation of HRM processes and practices (Darino et al., 2019). Agile HR is people-centric (Dank & Hellström, 2021) and based on the employee experience (Dank & Hellström, 2021; Morgan, 2017), as evidenced by the case studies presented in a previous section.

The architecture of an Agile organization is flexible, networked (Dank & Hellström, 2021) and organized on the basis of projects (Cappelli et al., 2018) in multi-professional and multidisciplinary teams, as proven by the Agile transformation process in the BBVA and ING Groups. This form of organization allows for the co-creation and sharing of knowledge, but it can be a challenge in terms of assigning and defining roles, as teams vary depending on the project and the same worker can take on different responsibilities depending on the project they are involved in. Even with fewer members, Agile teams are better suited to innovation, as they are directed towards the profitable application of creativity to improve products and services, processes or business models (Rigby et al., 2018).

As mentioned by Captelli et al. (2018) in relation to the IBM Group, Agile HR is organized in flexible structures, with the focus on the customer experience. Structural flexibility requires organization, with well-defined rules and routines to develop an organizational environment of trust and transparency. That said, when pre-established rules are followed, a high-performance environment and organizational stability are

guaranteed. As discussed in the present chapter, HRM professionals play a key role in the implementation, operationalization and sustainability of Agile and help ensure organizational stability.

There is a diversity of Agile tools and it is unlikely to apply them in exactly the same way as they are implemented in software development, as these are different areas of activity, with different projects and clients (Jafa et al., 2021). In short, it should be noted that even if HR professionals use the Agile tools presented here, this does not mean that HR is Agile, because being Agile requires much more than that.

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Mapping and Conceptualising Eco-Innovation Practices on Environmental Performance

Abraham G. Pamba and Ismail W. R. Taifa

Abstract Eco-innovation is the development of novel concepts, approaches, methods, attitudes, practices, goods, or procedures that ameliorate environmental burdens while enhancing economic efficiency. This study scrutinises the influence of eco-innovation practices on environmental performance. The emphasis is on eco-innovation activities, implementation challenges, and successful implementation strategies. A qualitative method gathered the findings. To identify and analyse articles from the Web of Science and Scopus databases, this study utilised scientometric, bibliometric, and visual analytic tools between 2000 and 2022. The bibliometric results show that eco-innovation in publications started in 2000 and increased dramatically from 2017 to 2021. The scientometric analysis found various eco-innovation activities, such as implementing green technologies and having environmental management systems. The analytical process demonstrates that people are not very aware of the eco-innovation significance. Most studies reveal that industries seem not to be taking environmental activities whenever there are no clear linkages with their benefits. Eco-innovation entails more than simply adhering to environmental regulations. Being environmentally innovative and gaining market share through such innovation is extremely challenging. Additional difficulties relate to the market, raw materials, and governmental and internal industry indicators. The four groups promoting eco-innovation are policy-making, environmental management, communication, and market and technological innovation.

Keywords Innovation · Eco-innovation · Mapping eco-innovation · Conceptualising eco-innovation · Environmental performance · Manufacturing industries · Environmental sustainability · Scientometric · Bibliometric · Visual analytic tools

A. G. Pamba · I. W. R. Taifa (✉)
Department of Mechanical and Industrial Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania
e-mail: itaifa@udsm.ac.tz; taifaismail@yahoo.com

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1 Introduction

The major sustainability tenets are the economic, social, and environmental values (Taifa et al., 2020b, 2021a, 2021b). Such tenets are sometimes referred to as the 3Ps of sustainability: the Ps refer to People (social), Planet (environmental values), and Profit (economics), also often stated as the triple bottom line. Sustainability should significantly protect and maximise the 3Ps' benefits. So far, research has addressed several economic and social issues, including corporate social responsibility and economic growth, concerning the seventeen sustainable development goals (SDGs) (Taifa, 2021). However, due to the global concern mainly for the current and future generations' sustainability, practitioners and academics are comprehensively researching sustaining the environment. Eco-innovation is among the most explored contemporary issues (Fussler & James, 1996; Sharma et al., 2021). Eco-innovation refers to creative initiatives that promote environmental sustainability, green solutions, and long-term thinking (Janahi et al., 2021). Eco-innovation is a relatively novel concept to several sectors, mainly during the late twentieth century. However, it has been a rising concern among policy-makers, researchers, and practitioners in several sectors, including the manufacturing industry (Xavier et al., 2020; Yurdakul & Kazan, 2020). It is a topic of great importance due to its potential for environmental benefits (Janahi et al., 2021; Sobczak & Głuszczuk, 2022; Wysocki, 2021). Promoting eco-innovation and implementing it in businesses is necessary in light of growing concern over the planet's environmental future. External knowledge, open innovation, and research and development (R&D) collaboration are important eco-innovation drivers (Chistov et al., 2021).

Socially responsible businesses are developing new services, products, and manufacturing processes in response to environmental concerns to preserve and enhance the quality of the environment (Mačiulytė-Šniukienė & Sekhniashvili, 2021). It is essential to improve the product life cycle to enhance the environment. In some scenarios, reducing environmental impacts in one phase can inadvertently shift the effects to another—a life cycle viewpoint aids in recognising these potential trade-offs. Thus, quality improvement, mainly continuous improvement, must be prioritised (Taifa & Lushaju, 2020), and if possible, for the twenty-first century, Quality 4.0 can be adopted as part of Industry 4.0 to the quality transformation (Taifa et al., 2020a; Maganga & Taifa, 2023b, 2023c, 2024; Nhelekwa et al., 2022).

Eco-innovation efforts can boost environmental performance depending on the implementation level, practices, and methods (Geng et al., 2020). In companies' operations, sustainable innovation initiatives have become critical competitive elements for long-term success (Ch'ng et al., 2021). The internal setting, strategy, operations, and structure are the four aspects that makeup eco-innovation capabilities (Ceptureanu et al., 2020), while process, organisational, and product practices are three types of sustainability-driven innovation practices (Ceptureanu et al., 2020). The eco-innovation strategy describes business commitments and actions to realise innovation that targets and promotes sustainable development (Janahi et al., 2021).

Several researchers, e.g., Triguero et al. (2013), Pipatprapa et al. (2016), Aryanto et al. (2021), and Li et al. (2021), have explored eco-innovation practices in different manufacturing and processing industries the extent to which eco-innovation practices in industries account for healthy eco-system and challenges that face such industries. However, organisations face various challenges when analysing eco-innovation approaches for a comprehensive picture of environmental sustainability, green solutions, and long-term thinking. Significantly, the theoretical underpinnings seem inconsistent regarding the nature of this study's practical goals and topics linked to eco-innovation strategic plans and practices in the processing and manufacturing industries. Environmental sustainability is crucial for maintaining a better eco-system over a longer period (Athuman et al., 2024; Taifa, 2020; Taifa et al., 2021a, 2021b).

While it is acknowledged for the massive research on innovation-related studies, there is still a need for conceptualising eco-innovation practices in various sectors. For example, Fussler and James (1996) presented the idea of eco-innovation mainly on driving eco-innovation as part of a breakthrough discipline for sustainability and innovation. Since then, researchers and academics have comprehensively researched and disseminated their findings. Rennings (2000) redefined innovation and eco-innovation, mainly how the two can contribute to ecological economics. Rennings's (2000) study also highlighted the significance of eco-innovation on sustainable development. The four major clusters of organisations, i.e., manufacturing, service, supply, and transportation, have all received great attention. Sanni and Verdolini (2022) studied eco-innovation and openness mainly by mapping the knowledge structure of open eco-innovation and the growth trajectories. Other examples of research on the eco-innovation theme include the studies by Carrillo and Carrillo-hermosilla (2009), Arundel and Kemp (2009), Ekins (2010), Peiro-Signes et al. (2011), Mogensen and Rousse (2012), Jasiński and Tużnik (2013), Dong et al. (2014), Pinget et al. (2015), Dahan and Yusof (2016), Long et al. (2017), García-Álvarez and Moreno (2018), Hazarika and Zhang (2019), Xavier et al. (2020), Janahi et al. (2021) and Sobczak et al. (2022).

Likewise, other studies focus on the eco-innovation concept's individual context. For example, Janahi et al. (2021) developed *strategies* for the manufacturing industries, Sanni (2018) proposed *drivers* of eco-innovation in manufacturing factories, Tumaini (2021) provided *barriers* to green manufacturing for Tanzania's manufacturing factories, Awogbemi et al. (2022) studied management of resource recycling to attain zero-waste manufacturing. Namagembe et al. (2019) studied companies' performance by adopting green supply chain practices in manufacturing small-scale and medium-sized enterprises (SMEs) in Uganda. De Jesus et al. (2021) also stated the eco-innovation diversity in a circular economy.

Notwithstanding their crucial contributions to academia and sustainable development, their studies seem to have not, first, conceptualised and mapped eco-innovation practices on environmental performance utilising scientometric, bibliometric, and visual analytic tools. Second, performed a systematic theoretical background with specified periods, e.g., for several years, how have practitioners and academics researched and published through some reputable databases, e.g., Scopus, Web of Science, and Google Scholar, among others. Third, most did not link eco-innovation

with environmental performance, specifically for the manufacturing industries. So, the above gaps motivate and form the foundation for extending eco-innovation studies.

Therefore, due to the need to conceptualise, map, and explore the novelty of the eco-innovation research theme, this research examines the impact of eco-innovation practices on environmental performance through a systematic literature review, chiefly in manufacturing industries. The study ascertains the answers to the following research questions (RQs).

RQ_1 What are the eco-innovative activities used by industries to enhance environmental performance?
RQ_2 What are the challenges hindering industries from being eco-innovative?
RQ_3 What strategies and policy initiatives promote eco-innovation in industries?

The other study's sections are organised as follows. The theoretical underpinnings are in Sect. 2, whereas the applied methodology is dictated in Sect. 3. Section 4 discourses the findings and discussion. Lastly, Sect. 5 depicts the concluding remarks, the study's significance, limitations, and recommendations for this study.

2 Theoretical Orientation

2.1 Eco-Innovation Overview

Since the time Fussler and James (1996) presented the idea of eco-innovation in their book "*Driving eco-innovation: a breakthrough discipline for innovation and sustainability*", it has grown in popularity. Various definitions of eco-innovation have emerged in recent years. A number of authors have proposed a comprehensive meaning of eco-innovation. Dahan and Yusof (2020) adopted the definition of eco-innovation as the strategic and operational application of any non-technical and technical change that is either new to the firm or new to the world, aiming at attaining a balanced financial returns priority, sustaining the environment, and societal well-being that results in long-term social, environmental, economic, and institutional profits. When glancing at how the global economy is changing in the face of constant technological advancement, addressing climate change, depleting resources, and striving for a low-carbon economy, eco-innovation is becoming increasingly important (Janahi et al., 2021).

A study by Hazarika and Zhang (2019) developed an analytical framework with an eco-evolutionary approach. The eco-evolutionary method is operative because it includes all subsystems cooperating with one another without any ranking or hierarchy of status for any of the subsystems, thereby eliminating technological bias (Hazarika & Zhang, 2019). A socio-economic context can excellently affect technological eco-innovations, decision-makers, and institutional and organisational intent (Hazarika & Zhang, 2019). Such eco-innovations interact to increase sectoral

variation, improve product or process design, increase economic viability, and increase regulatory involvement for higher diffusion. These repercussions impact consumer behaviour and lifestyle choices, leading to social eco-innovation, which in turn influence the connections of institutional, technological, and organisational eco-innovations over selective pinning.

Hazarika and Zhang (2019) state that the developed analytical framework with an eco-evolutionary approach consists of four components: economic sustainability, product sustainability, system change, and sociotechnical landscape. For the part of the actors, there is regulatory pull for the demand, which includes business strategies, waivers or subsidies, target setting, network building, demand itself, and life choices. Likewise, there is radical eco-innovation for the resources, which comprises product design, product network, absorptive capacity, total quality management, Environmental Management System (EMS), and demand side management. The inner part of the framework comprises four pillars: technological eco-innovation, institutional eco-innovation, social eco-innovation, and organisational eco-innovation.

Xavier et al. (2020) developed a maturity model that acts as a framework for integrating eco-innovation and improving organisational maturity. This aids in overcoming organisational barriers to eco-innovation implementation holistically, as well as operational barriers to eco-innovation implementation and global integration, such as a lack of maturity models, prescriptive methods, and support tools (Xavier et al., 2020). Xavier et al. (2020) eco-innovation model classified it into five levels (1 to 5), and each level had four issues: strategies, structure, resources, and culture.

Eco-innovation includes process innovation in manufacturing to create sustainable products (Fernando & Wah, 2017). Thus, eco-innovation involves the creation, adoption, or application of a new service, process, product, or management and business strategy that seeks to avoid or significantly reduce risk to pollution, the environment, and other adverse effects of resource use over the course of its lifecycle, including energy (Ekins, 2010).

Eco-innovation refers to inventions that have a lesser environmental effect than competing options. The ability to innovate and the pressure to innovate were used to divide eco-innovation in the study by Fernando and Wah (2017). Technology, cross-functional collaboration, and market focus are all components of innovation capacity. Regulation is incorporated as a means of incentivising innovation. As explained below, five activities have been identified as the key drivers of eco-innovation.

(a) *Cross-functional coordination* can be characterised as an attitude that views combination as a "partnership" (a collaborative process with shared aims and objectives) or as a behavioural method that describes the intensity of information sharing and interaction between the players (Olson et al., 2001). Knowledge transmission and networking decisions on innovation are influenced by cross-functional collaboration (Horbach et al., 2012).
(b) *Market focus:* consumer views of innovation and its attributes assist businesses in determining market needs and desires for environmentally friendly products (Doran & Ryan, 2012). Green technology companies must discover what

the market wants and target certain groups to service (Carrillo & Carrillo-hermosilla, 2009). Eco-innovations that are more market-focused are more likely to succeed in the marketplace.

(c) *Regulations offer:* companies with useful and normative material, for example, issue-specific rules and stringent standards for all pollutants and eco-innovators, so they know what is not and what is necessary (Fernando & Wah, 2017). The spread of strict policy regulations can pressure businesses to innovate in environmentally friendly technologies while similarly increasing domestic firms' competitiveness (Beise & Rennings, 2005).

(d) *Supplier involvement:* acquired materials and components from suppliers have a significant impact on a manufacturer's product quality, competitiveness, market availability, development risks, cost reliance, product design, lead times, and development cycles (Pujari, 2006),

(e) *Technology*: companies that invest in R&D and technology foster additional innovation (Doran & Ryan, 2012). Companies can capitalise on internal R&D, which keeps the inventive activities to generate new goods within the company, or extramural R&D, which outsources creative labour.

A cross-sectional survey by Maxwell et al. (2006) on resource usage and waste generation in the manufacturing industries in Malaysia found that manufacturing industries accounted for 61% of the world's natural resources and waste generation. Maxwell et al.'s (2006) study further noted that manufacturing industries were responsible for 36% of global. Such a study concluded that if manufacturing industries do not devise a framework through which eco-innovative activities should be adopted, environmental life and performance would have an adverse effect.

García-Álvarez and Moreno (2018) highlighted eco-marketing innovation tactics that induced clients to acquire eco-innovative items. This meant that pricing, quality, delivery, and the industry's green image and sustainability influenced a customer's purchasing decision. However, the study further reiterated that even though the customers were driven by eco-marketing innovation, several industries had not ventured into such a framework. Similarly, Arundel and Kemp (2009) stipulated eco-innovation activities as presented in Fig. 1.

2.2 Challenges of Eco-Innovation

From an analytical framework by Jansson and Carlberg (2019), three different themes were used to present challenges (Fig. 2). The themes cover issues with the company or organisation, the goods, and their production, as well as diffusion and adoption.

(a) ***Awareness***

Industries have become more conscious of the environmental impact of their operations recently. In fact, many industries are still unaware of the numerous advantages

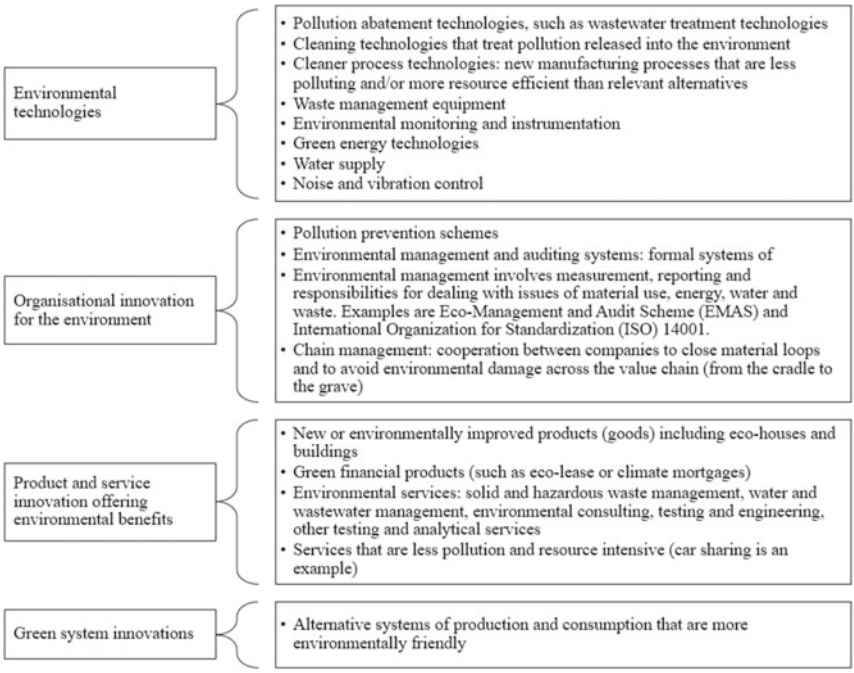

Fig. 1 Classification of eco-innovation based on activities. *Source* Created by the authors

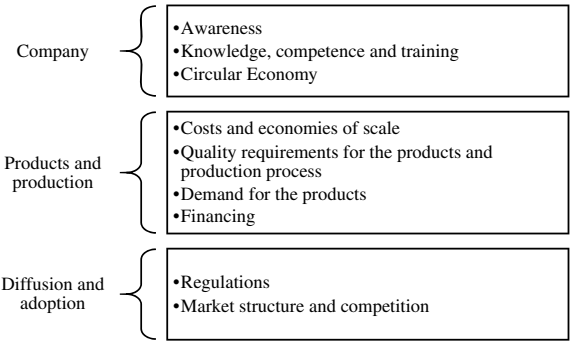

Fig. 2 Challenges of eco-innovation. *Source* Created by the authors

of incorporating eco-innovation practices into their operations (Carrillo & Carrillo-hermosilla, 2009). Regardless, the nonexistence of understanding of the industry's environmental impacts and measures to mitigate them is frequently an impediment to eco-innovation (Carrillo & Carrillo-hermosilla, 2009).

(b) ***Knowledge, Competence, and Training***

Many industries lack adequate knowledge of eco-innovation. For instance, many industries are uninformed of the necessary transformation to conform to the environmental requirements and eco-innovation impressions (Jansson & Carlberg, 2019). The lack of knowledge could be attributed to a lack of eco-innovation training along with the industry's learning-by-doing method. This learning-by-doing strategy, in which industries learn by performing tasks rather than through a trainer, is unsuitable for large transitions to an eco-innovation business model (Jansson & Carlberg, 2019).

(c) ***Circular Economy (CE)***

The CE aims to transform manufacturing procedures and consumer behaviours into a closed-loop structure. It is a material recirculation in the sense that old materials are recycled to create new products (De Jesus & Mendonça, 2018). Industries that adopt such a principle encounter obstacles like high initial costs, infrastructure that requires a lot of resources, trouble with cross-company collaboration, and a lack of customer enthusiasm.

(d) ***Cost and Economies of Scale***

A barrier to innovation is the cost for businesses to create a more environmentally friendly product. For businesses of all sizes with an eco-innovative strategy, the absence of economies of scale for product manufacturing can be challenging (De Jesus & Mendonça, 2018). Economies of scale are regularly advantageous when it comes to existing technologies that are not environmentally innovative. Thus, prices fall, and the quality increases. Nevertheless, since implementing eco-innovation technologies is incredibly expensive, there are no economies of scale in eco-innovation, which is viewed as an emerging technology (De Jesus & Mendonça, 2018).

(e) ***Product Quality Requirements and Production Processes***

Companies are confident that the components and designs meet their needs. As a result, they would have to spend money to change something that is already upright. Therefore, scepticism about new eco-innovative resolutions stems from a lack of industry experience (Jansson & Carlberg, 2019).

(f) ***Customer Demand for the Products***

It is difficult to persuade customers to accept eco-innovative solutions. This is because, compared to other products, eco-innovative products are relatively new, with some market uncertainties (Klewitz et al., 2012). Klewitz et al. (2012) highlight that some manufacturers assert that their customers may not want eco-friendly goods and that this is not important to them.

(g) ***Internal Financing***

The difficulties in accessing capital that can account for eco-innovation, which is necessary for its application, is one of the major difficulties in many industries.

(h) ***Regulations***

It is challenging for industries to introduce novel solutions when there is a slow response to regulation. Because some industries might not have the necessary knowledge to react quickly to changes, it can be challenging to adapt to new laws. Some industries struggle to compile the necessary data, modify their operations and output in accordance with the new regulations, and comprehend the implications of the new rules for their respective industries (Jansson & Carlberg, 2019).

(i) ***Structure and Competition in the Market***

Markets for environmentally innovative industries are frequently complicated and changing, an issue that industries must recognise and resolve (Pinget et al., 2015). The market value of the company's environmentally friendly goods will decline because of increased market competition because customers will have more replacement options. Even though businesses must produce more customer demand to keep up with the competition, increased competition drives up marketing costs (Jasiński & Tużnik, 2013).

A case study by Hoffman and Ehrenfeld (2017) indicated that the future of processing companies in the UK was questionable due to the high amount of non-recyclable plastics discarded. Of course, that was due to a report on the sustainability of the processing industries in the UK (Hoffman & Ehrenfeld, 2017). However, Hoffman and Ehrenfeld's (2017) study further reiterated that the sustainability of processing companies was to be addressed by solving issues related to developing bio-degradable packaging materials and reducing waste and solid disposal control. The study also highlighted that the government tax on such industries impacted their production due to global market competition. Hoffman and Ehrenfeld's (2017) study concluded that every processing company should diligently hire highly qualified and technologically innovative personnel to initiate and implement the production process that would not harm environmental life.

3 Research Methodology

In general, a qualitative approach collected data to map eco-innovation as a benchmark that industries can use to achieve sustainable manufacturing and improve environmental performance. The study utilised scientometric, bibliometric, and visual analytic tools to categorise and assess collected literature from Scopus and WOS.

3.1 Exclusion and Inclusion Criteria

We first discussed and created the study's inclusion and exclusion criteria to map eco-innovation (Islam et al., 2021; Maganga & Taifa, 2023a; Athuman et al., 2024). The inclusion criteria comprise the timeframe of 2000–2022. Such a range of years was

chosen due to the study's nature (Taifa et al., 2020c), as several published research were executed during such a period of eco-innovation practices. Educational journal articles offer a vast amount of information on a wide range of topics that are adequate for attaining the study's aim, while the general peer manuscript review processes guarantee a certain quality level when choosing literature materials (Islam et al., 2021). There is also the inclusion of book chapters, companies' annual and progress reports, and international conference proceedings. To ensure wide coverage of pertinent papers for inclusion, logical operators such as AND, and OR, wildcards such as *, and synonyms of environmentally friendly activities were deployed to determine the suitable published literature materials. The used keywords are "environmental performance", in the "manufacturing industry" and "eco innovation". For exclusion criteria, this comprehensive and systematic review excluded short surveys, non-full articles, lecture notes, reports, newspapers, books, articles not written in the English language, duplicate entries, and medical articles. Non-relevant articles, such as journal articles that did not mention eco-innovation and/or environmental performance, were also excluded.

3.2 Sources of Information for This Research

The main scientific journals database was used to gather information, with published articles extracted from Scopus and WOS to visualise theme evolution and compositional clusters connected with "eco innovation".

3.3 Conducting Search

Only published articles with the keyword "eco innovation" were searched; however, related articles found in the results, for example, environmental performance and subject areas like green sustainable technology, environmental science, environmental studies, and management, were also examined. Furthermore, the same criteria were utilised to screen articles from all sources to confirm the data and information gathered were reliable and accurate. A description of how the screening was carried out is shown in Fig. 3. Such approach of finding, screening, and analysing the gathered data was adapted from the previous studies by Taifa et al. (2021a, 2021b), Taifa (2021), Nzumile and Tafia (2021).

3.4 Bibliometric Analysis

The descriptive analyses glanced at how articles were distributed by the year of publication, authors' contributions, journals, and countries. Such analysis focuses on

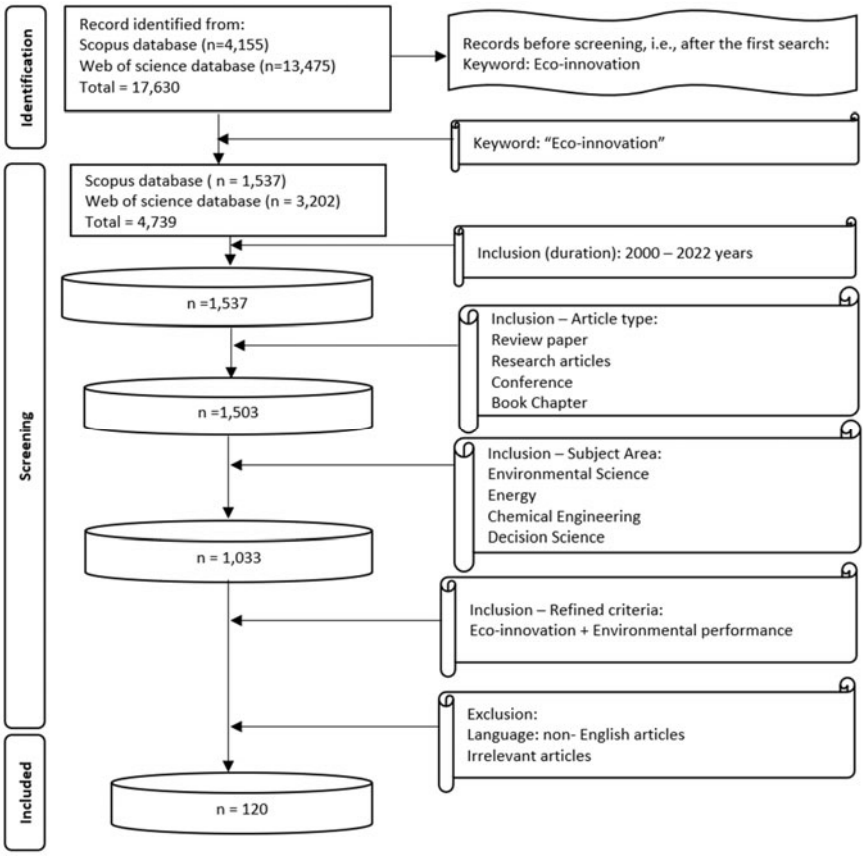

Fig. 3 Identification of studies via database and registers. *Source* Created by the authors

technological advancements, organisational, or institutional changes and provides a comprehensive synopsis of eco-innovations current situation and trends.

3.5 Scientometric Analysis

Definitions or explanations, models of eco-innovation, and eco-innovation's three dimensions: targets, mechanisms, and impacts associated with effects, challenges, and benefits of embracing the eco-innovation approach on environmental performance were all examined in the reviewed articles.

4 Results and Discussion

4.1 Analysis of Bibliometric

This entails analysing and contextualising contributions to the fundamental concepts of eco-innovation to represent the up-to-date state of research better and classify the most relevant themes.

4.1.1 Article Overview

The review looked at 120 articles, which are summarised in Table 1. Figure 4 depicts the title co-occurrence network. Figure 5 shows the most relevant sources. Table 2 shows the trend topics, Fig. 6 shows the most relevant words, and Fig. 7 shows the topic tree map.

4.1.2 Co-occurrence Network of Titles

Any term from the published articles (e.g., abstract or title) can be depicted by a "node", whereby the node's size presents the number of published literatures it consists. Nodes that are closer together have a higher degree of similarity than nodes that are further apart. The link thickness between several nodes indicates the likelihood that they will appear in the same published article or book together. Figure 4 represents the "co-occurrence network" based on the collected and analysed articles.

4.1.3 Most Relevant Sources

The majority of the published literature sources utilised in this study were obtained from journals ranked in the top quartile in their respective fields by Scopus's CiteScore® ranking system. Journal of Cleaner Production, Ecological Economics, and Sustainable Production and Consumption are all highly regarded journals for several studies chosen. Other studies' source titles were not considered by Scopus' CiteScore®system; rather, they were classified in the Emerging Sources Citation Index (ESCI) of WOS. Even though the eco-innovation concepts were recognised towards 2000, their environmental performance connection received little consideration in the first ten years after 2000. To date, fewer researchers have attempted to link eco-innovation to environmental performance. Only since 2017 have published the numbers for eco-innovation and environmental performance, as shown in Fig. 5.

Table 1 Some of the articles reviewed regarding eco-innovation

Authors	Description	Year	Source title
De Jesus et al.	They assessed the eco-innovation of biodigester technology, focusing on its deployment in the Brazilian cassava processing industries	(2022)	Clean Technologies and Environmental Policy
Ocicka et al.	Explored green innovations for the supply chain partnership in Poland	(2022)	Energies
Darmandieu et al.	They showed the way it pays to be circular in manufacturing procedures. Their study discussed the green jobs and eco-innovativeness as mediators of a cost-efficiency benefit for the small and medium enterprises (SMEs) in Europe	(2022)	Business Strategy and the Environment
Sobczak and Głuszczuk	The diversification of innovation activity and eco-innovation of SMEs in Europe	(2022)	Sustainability (Switzerland)
Sobczak et al.	Innovation level and eco-innovation of the economy as a foundation for the typology of the European Union (EU) countries	(2022)	International Journal of Environmental Research and Public Health
Mady et al.	Researched the eco-innovation and institutional pressure focusing on the facilitating green absorptive capacity role and strategic environmental orientation among the Egyptian industrial SMEs	(2022)	Cogent Business and Management
Munodawafa and Johl	Designed and developed an eco-innovation management information system to influence the companies' digital transformation strategies	(2022)	IEEE Access
Zheng and Iatridis	Executed theoretical underpinnings and meta-analysis of the connection between industrial performance and eco-innovation	(2022)	Business Strategy and the Environment
Rodríguez-González et al.	Researched the green supply chains as a facilitating variable to influence green strategies and eco-innovation on the financial performance and sustainability of the Mexican automotive industry	(2022)	Corporate Social Responsibility and Environmental Management
Tomala and Urbaniec	Performed a comparative analysis of eco-innovation development in selected European and Asian countries	(2021)	Ekonomia i Srodowisko

(continued)

Table 1 (continued)

Authors	Description	Year	Source title
Janahi et al.	Executed theoretical underpinnings on eco-innovation strategies in the manufacturing industry	(2021)	Cleaner Engineering and Technology
Tseng et al.	Investigated the moderating effects of absorptive capacity to check the strategic orientation, eco-innovation, and environmental management systems	(2021)	Sustainability (Switzerland)
De Jesus et al.	They studied how to transform into circular innovation	(2021)	Sustainability (Switzerland)
Isa and Abidin	Explored the components and drivers of adopting eco-innovation in Malaysian contractor firms	(2021)	Construction Economics and Building
Zhang and Gu	Developed a framework to recognise commercial growth position and path and adopt eco-innovations as the means towards micro-level green growth	(2021)	Sustainability (Switzerland)
Mačiulytė and Sekhniashvili	Explored the influence of eco-innovation influence on the environmental and economic performance of the European countries	(2021)	Business, Management and Economics Engineering
Bierwisch et al.	Their study performed a design-based workshop about eco-innovation to develop eco-innovative business models	(2021)	Sustainability (Switzerland)
Johl and Toha	The nexus between proactive eco-innovation and firm financial performance from the circular economy viewpoint	(2021)	Sustainability (Switzerland)
Arranz et al.	Explored the influence of market, internal, and institutional indicators on the growth of eco-innovation in companies	(2021)	Journal of Cleaner Production
Pichlak	Explored the technological eco-innovation indicators mostly by looking at the leadership and dynamic capabilities	(2021)	Sustainability (Switzerland)
Sun and Sun	Researched the executives' environmental awareness and eco-innovation from the executive by using an attention-focused assessment	(2021)	Sustainability (Switzerland)
Curado and Mota	Accomplished a theoretical orientation on sustainability in family companies	(2021)	Sustainability (Switzerland)

(continued)

Table 1 (continued)

Authors	Description	Year	Source title
Zhang et al.	Influences of manufacturing specialised and expanded agglomeration on the efficiency of eco-innovation practices through a dynamic nonlinear test viewpoint	(2021)	Sustainability (Switzerland)
Dec and Masiukiewicz	Studied socially responsible financial goods mainly on the way they contribute to attaining sustainable development	(2021)	Sustainability (Switzerland)
Wysocki	Studied the innovative green inventiveness in the Poland manufacturing small and medium-sized enterprise (SME) sector	(2021)	Sustainability (Switzerland)
Galera-Quiles et al.	Performed theoretical underpinnings of eco-innovations and exports interrelatedness, focusing on the supply chains of the international agri-food	(2021)	Sustainability (Switzerland)
Aryanto et al.	Studied the eco-innovation, entrepreneurship orientation, information and communication technology (ICT) learning adoption capabilities	(2021)	E3S Web of Conferences
Loučanová et al.	Explored the integration of eco-innovation and brand for enhancing branding and sustainability	(2021)	Sustainability (Switzerland)
Naruetharadhol et al.	Developed the open innovation and green management practice model to influence the open eco-innovation mode	(2021)	Cogent Business and Management
Li et al.	Studied the drives the environmental performance; the study focused on Asian countries	(2021)	Polish Journal of Environmental Studies
Sanchez-Planelles et al.	Developed a theoretical framework to enhance the sustainability of companies	(2021)	Sustainability (Switzerland)
Halicioglu	Explored the association between sustainability and eco-innovation in the construction industry	(2020)	IOP Conference Series: Earth and Environmental Science
Marín-Vinuesa et al.	They researched the dynamism capabilities and environmental accounting, mainly focusing on the business circular economy	(2020)	Sustainability Accounting, Management and Policy Journal
Maranesi and De Giovanni	This study focused on the modern circular economy for industrial symbiosis, supply chains and corporate strategies	(2020)	Sustainability (Switzerland)
Barba-Sanchez and Atienza-Sahuquillo	This study looked at the proactivity of the environment and economic performance, mainly from the Winery Sector	(2016)	Sustainability (Switzerland)

(continued)

Table 1 (continued)

Authors	Description	Year	Source title
Matjaz et al.	Conducted an empirical investigation of the sustainability-oriented innovation practices on the general organisational performance	(2016)	Total Quality Management & Business Excellence
Dong et al.	Assessed the influence of eco-innovation typology on its performance using empirical evidence from Chinese enterprises	(2014)	Journal of Engineering and Technology Management
Cai and Li	Studied the drivers of eco-innovation and its impact on performance using evidence from China	(2018)	Journal of Cleaner Production
De Jesus and Mendonça	Studied the drivers and barriers in the eco-innovation road towards the circular economy. They also discussed whether we are lost in the transition	(2018)	Ecological economics

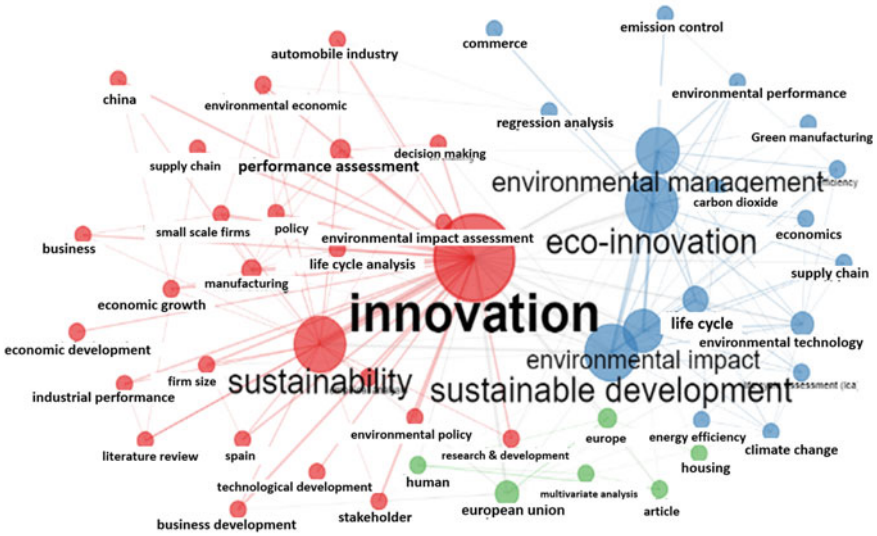

Fig. 4 Co-occurrence network. *Source* Created by the authors

4.1.4 Most Relevant Word

Table 2 depicts the most trending topics (themes). Eco-innovation literature on environmental performance has received more attention, followed by green innovation. Despite the findings in Table 2, there are few research that examine eco-innovation

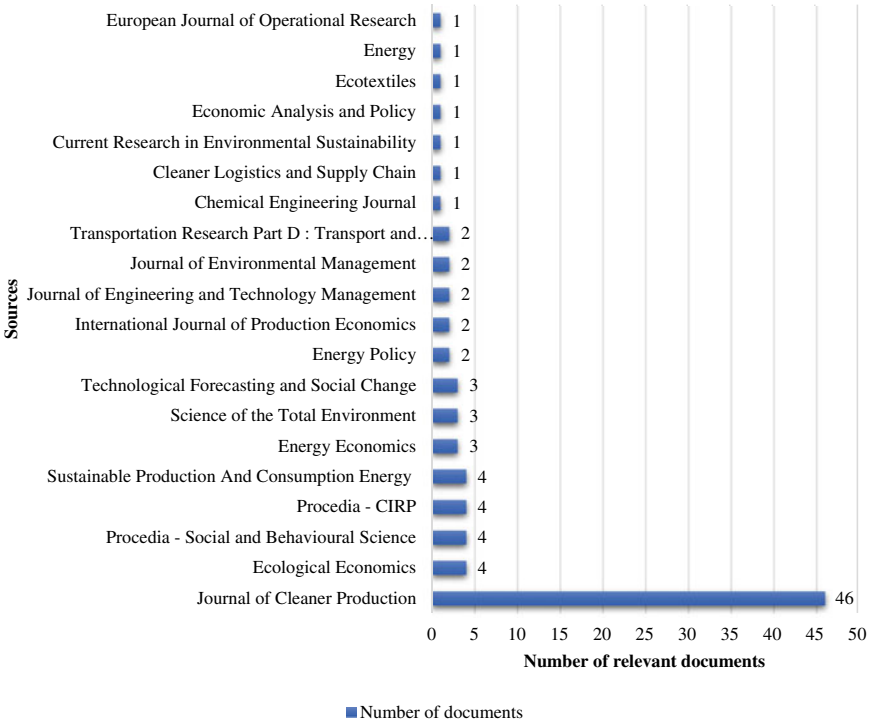

Fig. 5 Most relevant sources from the reviewed documents. *Source* Created by the authors

strategies. Thus, researchers need to map all related organisational strategic influences to eco-innovation. This is concerning, given that eco-innovation can benefit strategic organisational systems.

4.2 Scientometric Analysis

4.2.1 Eco-Innovative Activities Used by Industries to Enhance Environmental Performance

Organisations must shift their focus away from profit to achieve sustainable development. Industries must continue to pursue benefits without disregarding the interests of the people and planet because biosphere protection will affect industries' current and future competitiveness. This means the three major tenets of sustainability must be balanced: people (social), planet (environment), and profit (economics) (Taifa, 2021). Green technologies developed in industries, according to various authors such as Scarpellini et al. (2020), Vieira and Radonjič (2020), and Marín-Vinuesa et al. (2020), will consistently produce environmental performance benefits.

Table 2 Trend topics

Item	Frequency	Year_q1	Year_med	Year_q3
Sustainability performance	3	2012	2013	2017
Cycle assessment	7	2014	2015	2016
Life cycle	8	2014	2016	2017
Firm performance	6	2018	2018	2019
Environmental performance	27	2017	2019	2021
Financial performance	7	2018	2019	2022
Environmental innovation	6	2019	2019	2020
Mediating role	5	2018	2019	2021
Green innovation	13	2019	2020	2021
Economic performance	8	2018	2020	2020
Performance evidence	7	2018	2020	2021
Supply chain	6	2019	2020	2021
Moderating role	4	2020	2020	2020
Green process	6	2019	2021	2021
Process innovation	5	2020	2021	2021
Product innovation	5	2021	2021	2021
Sustainable development	4	2020	2021	2021
Green performance	3	2019	2021	2021

Costantini et al. (2017) measured eco-innovation regarding the patent stock for green technologies. Specifically, Costantini et al. (2017) examined the influence of environmental-specific technological innovations, for example, *combustion technologies with the potential mitigations* (e.g., technologies for the upgraded input and output efficiency); *technologies with indirect or potential influence to emission mitigations* (e.g., fuel cells, hydrogen technology and energy storage); *technologies contributive to climate-change mitigations* (e.g., capture, storage, disposal or sequestration of greenhouse gases); *emission abatement and fuel efficiency in transportation* (e.g., hybrid propulsion, internal combustion engines, electric motors, and fuel-efficiency-enhancement of the vehicle designs); *energy efficiency in lighting and buildings* (e.g., heating, insulation, and lighting); *and the general environmental management* (e.g., water- and air-pollution abatement, soil remediation, waste management, and monitoring the environment).

According to peer-reviewed articles (Table 1), eco-innovation practices include efforts to achieve improved or newly developed goods and services, altering commercial models, and executing eco-management in organisations or industries. Researchers must indicate the industrial-level data aggregated to show the country-level performance in the eco-innovation activities dimension, which is accomplished by establishing environmental management systems. As shown in Fig. 8, the number of the International Organisation for Standardisation (ISO) 14,001–environmental

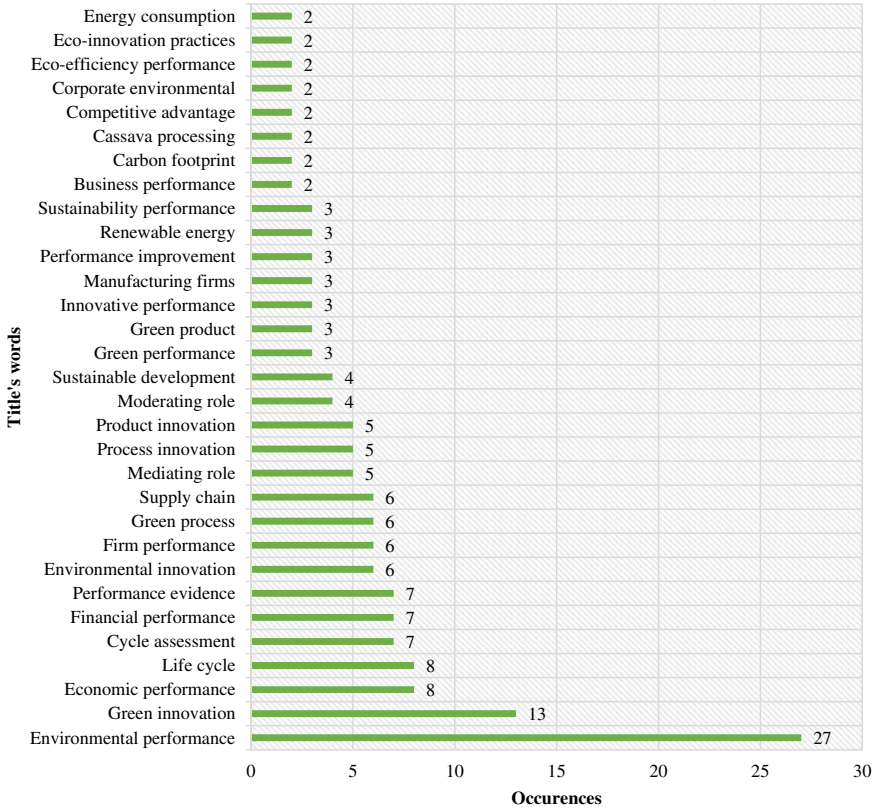

Fig. 6 Most relevant title's words from the reviewed documents. *Source* Created by the authors

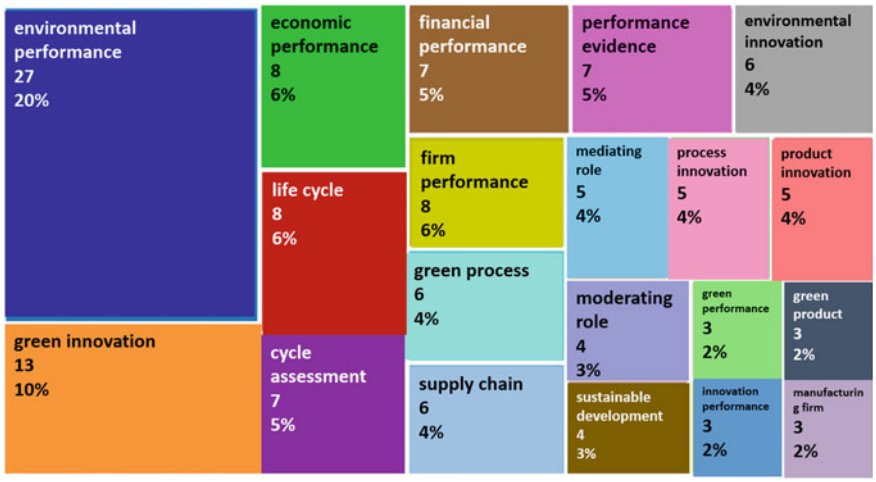

Fig. 7 Tree map of titles. *Source* Created by the authors

management systems certificates and sites has been increasing in main world regions (Mentel & Hajduk-Stelmachowicz, 2003).

Figure 9 depicts the various sectors with environmental management systems to satisfy those industries that should introduce environmental management systems as a prior activity to enhance environmental performance.

According to Ghisetti and Montresor (2019), the Eurobarometer survey depicted that 24% of the European SMEs (Fig. 10) have initiated eco-innovation in the form of novel goods or services, introduced eco-innovative manufacturing developments

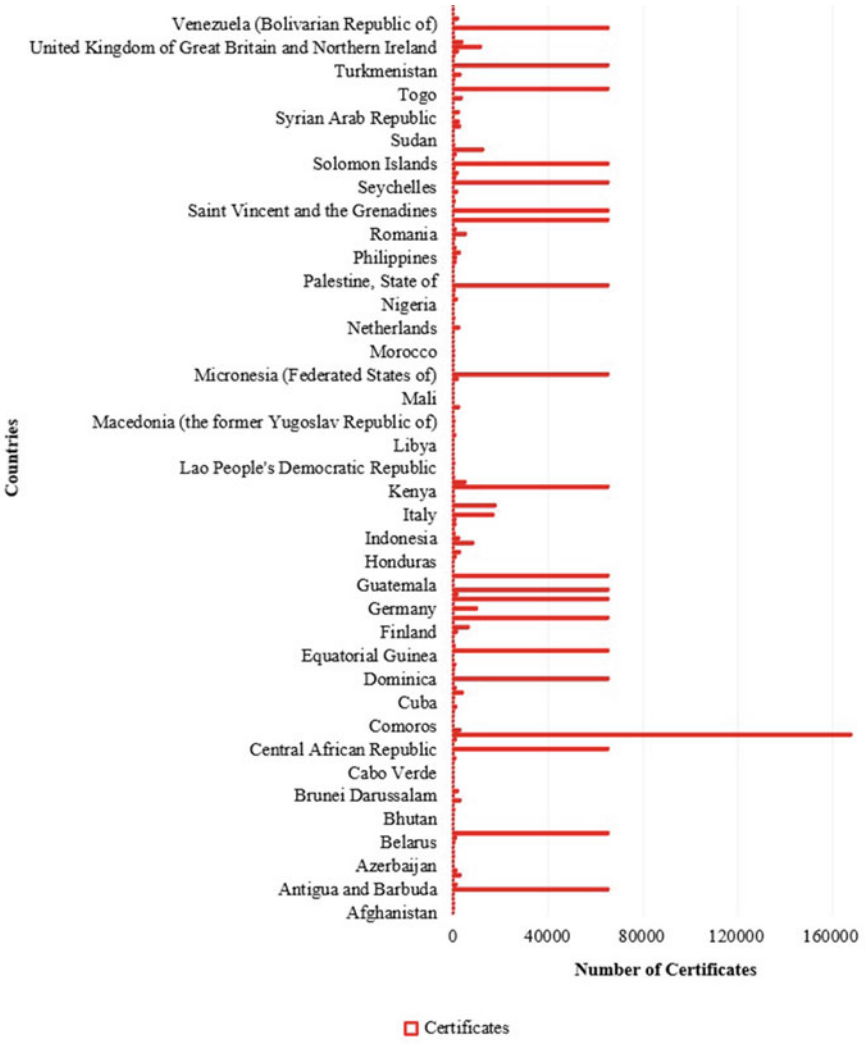

Fig. 8 Number of ISO 14001 in different countries. *Source* Created by the authors

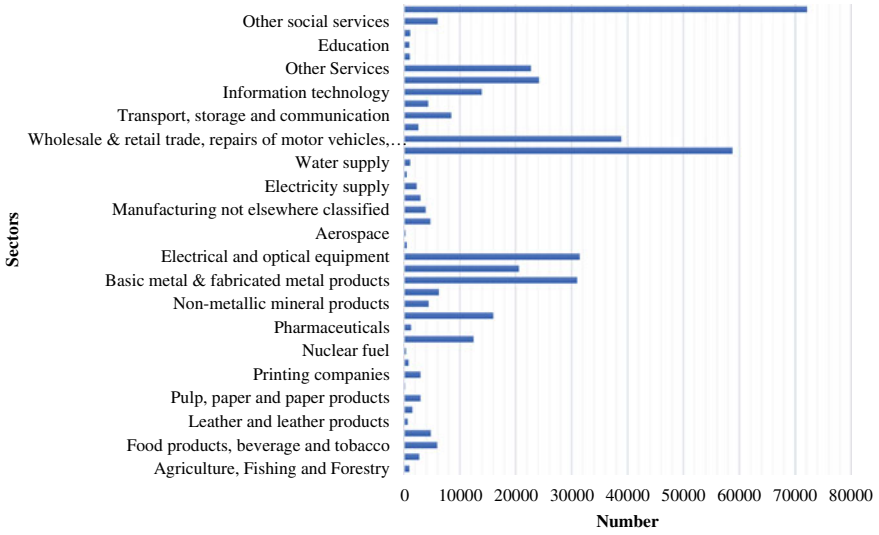

Fig. 9 Sectors with environmental management system. *Source* Created by the authors

(28%), and implemented eco-innovative organisational changes (22%). Other industries in different countries can use these activities to foster eco-innovation to enhance environmental performance.

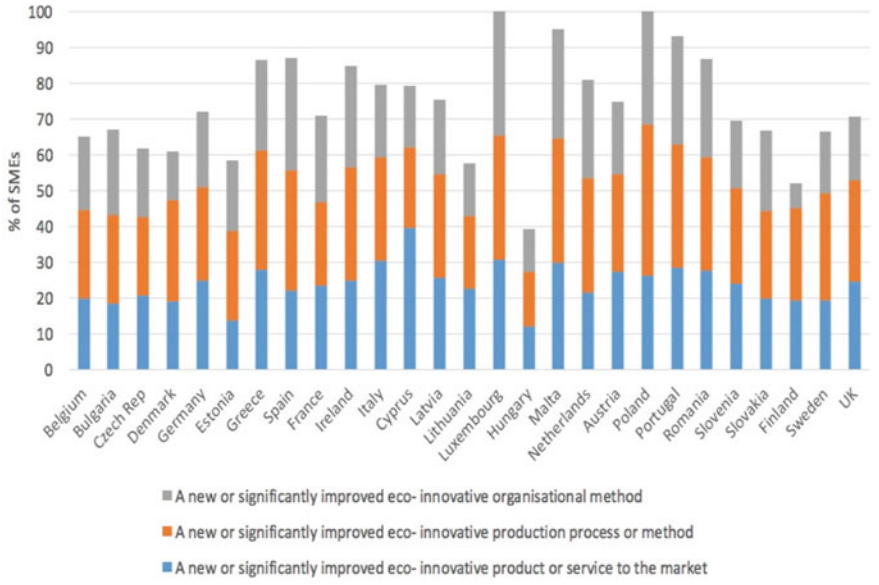

Fig. 10 Eco-innovation activities within SMEs. *Source* Created by the authors

Funding opportunities are available for eco-innovation and coping with technological advancement since it is a mover and shaker of eco-innovation worldwide. Furthermore, related policies are needed to support decision-making that implements eco-innovation within industries to improve such industries at local and national levels. Such policy matters should be combined with excellent innovative ideas for environmental performance.

4.2.2 Challenges Hindering Industries from Being Eco-Innovative

The articles (Table 2) were examined to learn more about the authors' perspectives on the barriers that prevent industries from being eco-innovative. Most of the previous research concentrated on eco-innovations and the indicators that drive them. However, research on eco-innovation barriers is limited, particularly among industries.

According to the findings, most people are unaware of the benefits of eco-innovation. Businesses hesitate to take environmental actions whenever there are no clear linkages with their benefits. Furthermore, action selection becomes a trade-off between environmental concerns and quality and delivery precision. On the other hand, eco-innovative solutions are relatively novel, and there is inexperience in this field. One of the other determined barriers is the transitions in processes that businesses must go through so as to be entirely eco-innovative. Such transitions present significant challenges for organisations that have long used the processes. Transitions appear to be time-consuming as well. Transitions appear to be time-consuming as well. Diffusion and adoption are barriers, making it difficult for businesses to upgrade and adapt their products to all markets (García-Álvarez & Moreno, 2018; Sanni, 2018; Triguero et al., 2013).

Eco-innovation is beyond compliance with environmental regulations, which all businesses must do. It all comes down to eco-innovative and capturing market share through environmental innovation, which is extremely difficult when regulations vary greatly (García-Álvarez & Moreno, 2018; Sanni, 2018; Triguero et al., 2013). It is thus challenging to be eco-innovative while complying with regulations and attaining scalability in the production processes in various industries. This complicates the implementation of long-term plans when new regulations are constantly introduced. Dugonski and Tumelero (2022) highlighted the following drivers and barriers to implementing technological eco-innovation.

(a) ***Macro Level (Government and Regulation)***: barriers include the deficiency of government support via tax incentives, inadequate access to subsides and financial incentives, and external funding issues, whereas the facilitators include the regulatory pressure (international and national standards, organisation and commercial agreements), legislation, public policies, and industry standardisation and organisation.

(b) ***Meso Level (Market and Technology)***: barriers include the deficiency of disclosure about subsides to reduce the use of materials and energy; market domination by traditional companies; uncertain demand; deficiency of cooperation; deficiency of specialised supply chain; and technological lock-ins. The facilitators comprise innovation chains and alliances with external and internal actors, competitive context, location, customer demand, patents, access to knowledge, technological opportunities, and technological cooperation.
(c) ***Micro-Level (Firm-Specific Factors)***: the barriers include lack of cooperation with research organisations; lack of suitable commercial partners; lack of external information technology and work; lack of skilled personnel and technological capacity; and semi-investment in eco-innovation projects.

4.2.3 Strategies and Policy Initiatives to Elevate Eco-Innovation in Industries

Examining eco-innovation strategies is distinct and necessary for industrial firms to consistently link environmental benefits with overall eco-efficiency improvement. Probing the articles (Table 1) with the goal of highlighting eco-innovation strategies in industries, various researches, e.g., Yang et al. (2022), Rabadán et al. (2020), Greco et al. (2020), and Janahi et al. (2021), argued that several managers asserted they likely do not have a complete understanding of what operative mechanisms and strategies could enhance eco-innovation in firms so that to deliver optimally eco-innovative and sustainable solutions. Industries should participate in and strategically execute eco-innovative procedures to improve economic performance. On the one hand, such strategic considerations drive current eco-innovation research into drivers such as environmental policies and regulation for implementing eco-innovation in industries (Janahi et al., 2021).

Eco-engineering Specifications and Skills Strategy: there is a need to protect the environment through the available engineering practices. In fact, the eco-bioengineering principles and standards can potentially enhance business restoration within the natural balance. According to Janahi et al. (2021), the design principles that can engage eco-bioengineering include designing in line with ecological principles, designing for site-specific framework, sustaining the independence of design functional necessities, designing for energy and information efficiency, and the values and purposes that motivate design.

Green Sharing of Knowledge and Sourcing Strategy: some researches link eco-innovation levels of patent applicants to "green knowledge sharing levels" (Cheng & Shiu, 2020; Rubashkina et al., 2015; Wurlod & Noailly, 2018). Likewise, Song et al. (2020) emphasise that superior eco-innovation performance focuses on the firm capability to absorb and optimising green knowledge in sharing within all supply chain nodes.

Environmental Regulations and Protection Strategies: environmental regulations involve institutional, organisational, and regional policies and strategies for participating in eco-innovation, and they are generally pertinent to latecomers who are

obligatory to adopt and comply with minimum environmental protection standards (Dangelico & Pujari, 2010; Janahi et al., 2021). Researches which notes environmental protection and regulations as important links to eco-innovation include those by Daddi et al. (2019), Mady et al. (2022), and Sobczak and Głuszczuk (2022). As a result, environmental regulations continue to be the most significant eco-innovation drivers and conducive environments that improve eco-innovation efficiency (Gupta & Barua, 2018). Nevertheless, studies show that environmental regulations have two impacts on eco-innovation technologies: compliance cost and innovation offset (Gong et al., 2018). Policies that guide decisions also provide opportunities for inducing industrial eco-innovation. Fiscal policies such as low-cost (subsidised) financing for innovation and fiscal incentives for sustainable practices are examples (Janahi et al., 2021). In a hybrid manufacturing system, there are also recycling policies that work in tandem with the carbon emission constraint mechanism (Zhang et al., 2019), and liberalisation policies in R&D sectors to enhance technological development (Janahi et al., 2021). Nonetheless, such policies necessitate reviews and enhancements via the organisational framework reflections and designs that mitigate political and informational risk (Amann et al., 2011).

4.2.4 Conceptual Framework for Eco-Innovation on Environmental Performance

Following a thorough examination and analysis of prior types of researches, a conceptual framework for assessing eco-innovation on environmental performance is established, as demonstrated in Fig. 11. Nevertheless, other researchers such as Sharma et al. (2020), García-Granero et al. (2020), and Šūmakaris et al. (2021) have provided other indicators, the ones highlighted in this conceptual framework (Fig. 11) are those that are considered pertinent to the phenomenon being measured. The developed framework for eco-innovation comprises six components: cross-functional team, technological aspects, environmental performance, regulation, market, and suppliers. These should work collaboratively to enhance eco-innovation within an organisation.

5 Conclusion, Implications, and Limitations

5.1 Concluding Remarks

This study mapped eco-innovation practices on environmental performance. The bibliometric results revealed that eco-innovation in many publications began in 2000 and increased dramatically from 2017 to 2021. The scientometric analysis found various eco-innovation activities, such as implementing green technologies and having an environmental management system. This study thus contributes in three ways to the eco-innovation perspectives. First, the study looks at the research clusters,

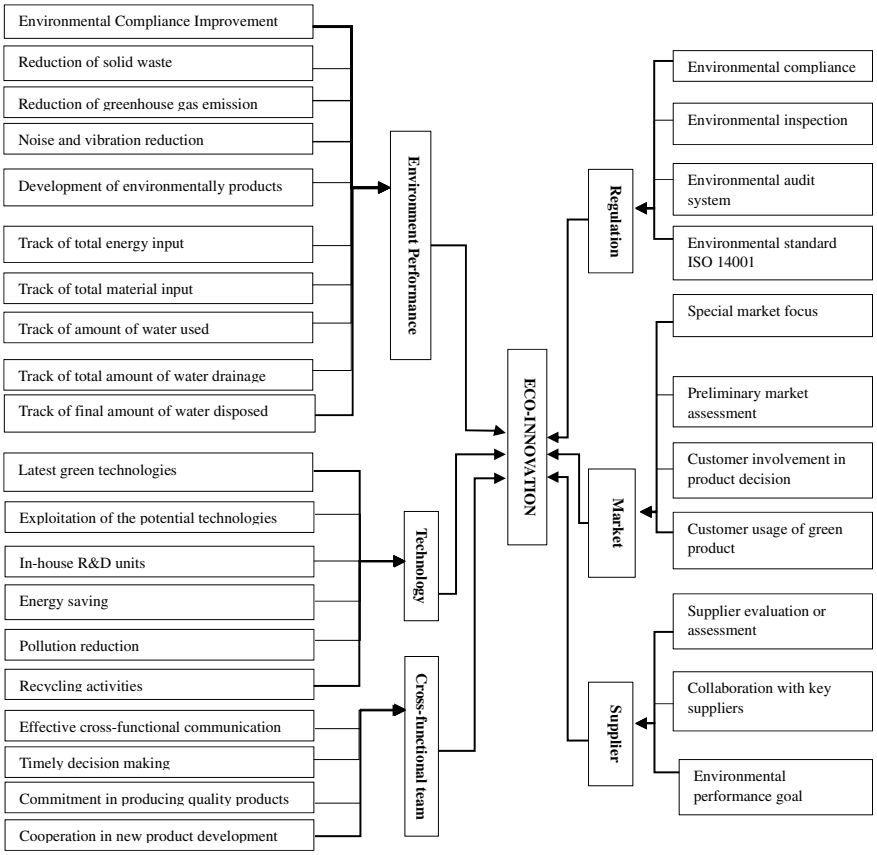

Fig. 11 Conceptual framework for eco-innovation on environmental performance. *Source* Created by the authors

methodologies, and theories which are utilised in the theoretical underpinnings of eco-innovation for industrial organisations. Based on internal, external, and bilateral factors, the analysis finds eco-innovation factors (activities) in the theoretical underpinnings that motivate or obstruct practices and research. Second, this study identifies barriers to eco-innovation, which aids in developing decision criteria and strategic options for encouraging eco-innovation to improve environmental performance. Third, this study suggests multi-level strategies for characterising and deepening eco-innovation execution. There is also a demonstration of how eco-innovation efforts can advance environmental performance; nevertheless, the performance focuses on the extent to which eco-innovation practices are implemented.

5.2 Implications to Practice and Society

This study will aid in a radical shift towards accelerating the development of sustainable innovations in industries through eco-innovation practices, methods, goods, and procedures that reduce environmental effects. This is due to the current requirements of sustaining the manufacturing processes and all the products by reducing energy and resource consumption. Eco-innovation implementation can save businesses costs in the long run through resource conservation and pollution prevention. Likewise, several practitioners and researchers may be equipped with eco-innovation practices to develop novel concepts, approaches, methods, attitudes, practices, goods, or procedures that ameliorate environmental burdens while enhancing economic efficiency. This is necessary because the current manufacturing practices must comply with the sustainability tenets: planet (environmental), people (social), and profits (economics). Firms together with other stakeholders, can thus integrate the stated open innovation strategies into eco-innovation processes for their firms or organisations.

5.3 Limitations of the Study

This study encountered the following limitations. To begin, eco-innovation is not only restricted to manufacturing organisations or research. Although this study focused on manufacturing organisations, it is strongly suggested to broaden the research area by exploring other geographies and different sectors, including services. Thus, that forms future study. Second, the literature sources reviewed in this study were sourced solely from Scopus and WOS databases. Third, this study concentrated on English-language publications. Fourth, this study was limited to empirical research, book chapters, and conference proceedings. Fourth, this study did not use any other synonyms for eco-innovation. Future studies could mitigate such constraints by replicating this study and incorporating Google Scholar databases and other reputable databases. Similarly, a multilingual research team can assist in including other studies published in non-English language articles. A multi-language team would address one language's shortcomings while broadening the scope of the articles under review to include more than one language. Finally, future studies may better understand the subject's evolutionary nature by using synonyms for eco-innovation.

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Managing and Engaging a Multigenerational Workforce in Portugal

José Rebelo Santos, Lurdes Pedro, and Célia Quintas

Abstract There are challenging changes in the job market with the multigenerational workforce, especially with the integration of new generations and the advancement of Artificial Intelligence, in an increasingly digital world. At a time when it is becoming more and more difficult for companies to find the human resources they need to operate, the first challenge being to hire and the second to retain those human resources, it is important to have a better understanding of characterisation of Generations X and Y, who currently dominate the labour market. The aim of this study is to understand what is valued by each of these generations, enabling organisations to develop strategies to match their needs with those of potential employees. HR departments and managers face new challenges to manage knowledge, skills, and attitudes, necessary in the organisations, to motivate, satisfy, and engage employees, from these different generations. A questionnaire was applied to a convenience sample of graduates from a higher education school. 421 responses were obtained and validated, allowing the respondents of Generations X and Y to be characterised. The data was statistically analysed, and it was concluded that Work–Life Balance, Autonomy, Work environment, Flexibility, Work time, Life at work quality, and Job Contents are highly valued, which corresponds to the reference literature. The results of their answers made it possible not only to characterise the sample, the differences, and the similarities but also to understand what they value when looking to join the labour market or change jobs.

Keywords Generation · Multigenerational workforce · Generation X · Generation Y · Millennials · Human resources management · Generational cohorts

J. R. Santos (✉) · L. Pedro · C. Quintas
Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Setúbal, Portugal
e-mail: jose.rebelo@esce.ips.pt

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1 Introduction

Organisations face major challenges due to the advancement of Smart Engineering Management and Artificial Intelligence processes. These challenges arise from the transformation of the production process, which has been replaced by smart technology. These changes are accompanied by changes in labour, requiring higher qualifications, and new demands. We know that several generations coexist in organisations, which introduces even more complexity.

In Portugal labour market and most Western countries profound changes have taken place, on the one hand, due to the individuals who are part of it, and on the other, due to a lack of labour and migration.

Today, most people belong to Generations X and Y. These Generations correspond to those born between 1960 and 1979 in the case of Generation X and between 1980 and 2000 in the case of Generation Y, according to the typologies proposed by some authors.

According literature Generation X values lifelong employment, which predominated when they entered the labour market. Generation Y, on the other hand, values flexibility, and a balance between personal and professional life (Limpinho, 2022; Meriac et al., 2010; Teixeira et al., 2014).

The aim of this study is to understand what factors contribute to attracting and retaining Generation X and Generation Y in organisations.

Identifying the main differences and similarities between what is valued by Generations X and Y will allow organisations to better understand the strategies to develop to attract and retain the human resources they need from the different generations.

An exploratory quantitative methodology was used, through an online questionnaire survey applied to graduates of a higher education institution, belonging to Generation X and Generation Y, to understand the variables they value, and which are important for them to remain in their organisation.

The first part presents the theoretical framework, where the trends in the literature regarding the characteristics of Generations X and Y are presented, as well as the characteristics of Generations X and Y in the labour market. Two trends in the supporting literature are presented: a predominant trend that defends the existence of differences in terms of individuals' expectations at work, according to their generational belonging (e.g., Ferreira, 2017; Goessling, 2017; Teixeira et al., 2014) and another trend that defends the fact that the differences between generations are not significant, emphasising other factors that help to explain potential differences (Badali, et al., 2022; Konsk et al. 2010; Mencl & Lester, 2014). Finally, we present the Human Resource Management (HRM) practices adapted to the characteristics presented and the challenges facing HRM, considering the demands arising from the evolution of changing organisational contexts.

The second section explains the methodology used and the information-gathering techniques, and the third section presents and discusses the results of the study where we relate the results obtained to the reference literature.

2 Conceptual Framework

The conceptual approach begins with a reflection on Generations X and Y and the changes produced by the emergence of Industry 5.0. The characteristics of Generation X and Generation Y in the labour market and the challenges facing HRM are also addressed.

2.1 Generations X and Y

In the following points, we propose to analyse the characteristics of individuals belonging to the Generation X who were born between 1960 and 1979 and Y who were born between 1980 and 2000 (e.g., Cannon & Kendig, 2018; Barriopedro et al., 2018). The convergence and synergies generated by the development of intelligent engineering, resulting from the development of digital systems and artificial intelligence, has brought significant changes to the daily lives of people and organisations. It is a process of change in production systems that is already hegemonic, even encompassing traditional products, and which has effects at an economic, social, and political level. Its impact is so intense and far-reaching that it is commonly referred to as the "4th Industrial Revolution" (Abramovici & Neges, 2015; Bernier, 2023). Intelligent production capabilities have become crucial to the competitiveness of industrial companies. Processes related to intelligent engineering determine modes, techniques, and methods of production (Abramovici & Neges, 2015). According to Bernier (2023) the changes that have been taking place also affect the nature and characteristics of employment, leading to the professional downgrading of some activities, the loss of certain jobs and the creation of others that require a different and higher level of training.

In terms of human resources, Industry 5.0 places greater emphasis on the importance of people, resulting in new challenges, such as the blurring of the boundary between work and private life, with changes in the relationship between the organisation and workers as a result of the development of digital platforms (Bernier, 2023). Resilient people with the ability to adapt are needed to respond to the changes generated by climate change, characterised by the emergence of extreme phenomena such as droughts, floods, fires, wars, disease, etc. (Suárez & Paredes, 2022).

There is a need to better understand the role of the human factor in conjunction with technology and value creation. These have some similarities with the perspectives on work and personal life of the younger generations.

This process necessarily affects all work contexts, posing new challenges for workers and HRM practices. In these moving and changing contexts, organisations are also faced with another challenge: generational issues and different perspectives and expectations in relation to work. Therefore, our aim is to understand what factors contribute to attracting and retaining individuals from Generations X and Y in organisations in this fast-moving world.

The Generation X, for Mhatre and Conger (2011) and Schoch (2012), cited by Abreu et al. (2016), has a sceptical behaviour that has been a situation of change, financial difficulties, making them pessimistic with no expectations of improvement. This generation was also the first to have more contact with technological innovations, owning a personal computer with Internet access (Oliveira 2008 cited by Abreu et al., 2016). In contrast, for Zemke et al. (2000) and Wallace (2006) cited by Abreu et al. (2016) Generation X is one that demonstrates self-confidence, an entrepreneurial and creative spirit.

Generation Y, on the other hand, according to Sweeney (2006), referred to by Abreu et al. (2016) is made up of individuals who are self-confident, structured, and flexible in relation to different cultures.

Generation Y, according to Glass (2007) and Zevenbergen (2004), cited by Abreu et al, (2016), has intrinsic and different characteristics compared to previous generations, so that the individuals who are part of it become less committed to the organisation to which they belong.

2.2 Workplace Characteristics of Generations X and Y

Analysing social dynamics based on the study of generations makes it possible to identify a group of individuals who share common characteristics related to age, historical period, location, and space, from which it is possible to observe a certain homogeneity. In fact, the division of social groups into generations takes place by separating all the individuals who were born in the same period and are consequently influenced by a particular and common set of historical, social, and cultural conditions (Hess & Jepsen, 2009), which mould their values, beliefs, and attitudes.

The concept of generation thus has a broad scope, being present in almost all spheres of life, economic, political, social, and labour. In relation to the labour sphere, we are interested in studying the challenges facing HRM (Dobrescu et al., 2021). At a time when the labour shortage in Portugal is becoming increasingly evident, especially in certain specific areas, we consider it pertinent to study Generation Y and Generation X, which are the predominant generations in the labour market, in order to understand what factors most motivate individuals from one generation or the other, and what contribution the study of generations can make to a better understanding of the factors that attract and retain workers.

Generation X characterises individuals born between 1960 and 1979 (Cannon & Kendig, 2018), who lived through historical periods marked by turbulence and successive economic, social, and political crises. This generation lived through the period that corresponded, for example, to the assassination of Martin Luther King, the Cold War, or the fall of the Berlin Wall and went through the period of transition to digital technologies. Family environments were also marked by change, with the increasing transition of women into the labour market, which meant that this generation grew up with less parental supervision. As we said, Generation X experienced the crises resulting from the generation gap, but also family crises, with a

less structured family environment and an increase in divorce rates (Peluchette et al., 2013), possibly due to the fact that their parents (from the baby boomer generation) invested more in their careers, to the detriment of the work–life balance. Generation Y is the generation born between the early 1980s and the year 2000 (Barriopedro et al., 2018; Prakash & Tiwari, 2021; Souto, 2018; Stewart, 2017). It is a generation that lived through the turn of the millennium and has the particularity of being the last generation of the twentieth century, often referred to as the Peter Pan generation, in reference to the fact that many of the individuals born during this period continued to live with their parents in early adulthood, mainly due to economic factors. Given their strong contact with digital media, they are also commonly referred to as the Netgeneration (Graybill, 2014; Lamm & Meeks, 2009). A Geração Y was the first to grow up in the Internet boom era, with immediate or almost immediate access to technology, living in a technological and globalised environment (Lukas, 2022). It is understood in this work that globalisation, at least in part, is the result of significant technological development. It is estimated that by 2025, 75% of the workforce will belong to Generation Y (Hobart & Sendek, 2014; PwC, 2011). Data from Pordata indicates that in 2023 in Portugal the 25–34-year-old workforce will account for 20% and the 35–44-year-old workforce 26%.

Generation Y is the most heterogeneous in history in terms of culture, race, and ethnicity, and is even known as the "*Melting Pot Generation*" (Nielsen Company Report, 2014).

There is no consensus on the differentiating characteristics in socio-professional terms of generations based on the reference literature (Barriopedro et al., 2018; Limpinho, 2022; Machado, 2020). In fact, some authors argue that there are differences between generations (e.g., Teixeira et al., 2014, Cappi & Araújo, 2015; Limpinho, 2022) and others argue that there are no significant differences, on the contrary, there are more similarities than differences (e.g., Badali et al., 2022; Dick, 2019; Kelan, 2014; Kowske et al., 2010).

There is also no consensus on the historical context that allows generations to be defined and there are differences in the periods defined for Generational cohorts. Identifying individuals born in the early 1980s as Generation Y is different from identifying individuals born in, for example, '86 as belonging to this generation, since the internet only began to be used in Portugal in the mid-1980s and in a very modest way (Almeida, 2005).

On the other hand, the explosion of the Internet has not occurred uniformly throughout the country, nor has access been homogenous for all people. It has occurred more intensely in large urban centres and on the coast and less intensely in rural areas and in the interior, thus being a process marked by discontinuities and territorial inequalities. Notwithstanding the issues mentioned above, which we should point out, Generation X and Generation Y are, as mentioned, dominant in the labour market and the literature shows a certain generational homogeneity depending on whether they belong to one generation or the other, which allows individuals to be characterised differently depending on this variable.

Below we will identify a set of elements that seem to characterise and distinguish each of the generations, since they are common to a considerable proportion of their members (Cappi & Araújo, 2015; Limpinho, 2022; Teixeira et al., 2014).

According to Teixeira et al. (2014), Generation X has the following characteristics with regard to work:

(i) **Independence**—Children of the baby boomer generation, they inherited the appreciation of work as a means of professional advancement;
(ii) **Concern for Self-Esteem**—The development of their self-esteem as a way of empowering themselves and marking their personal and professional position is a concern;
(iii) **Information and Relationship with Managers**—They need a lot of information, but also flexibility, and as a result tend to reject excessive supervision;
(iv) **Adaptation to Change**—Some ability to adapt to change, including changing jobs, so they tend not to be very loyal to their employers;
(v) **Technical Skills**—They have strong technical skills and are potentially entrepreneurial;
(vi) **Individualists**—In the sense that they prefer to work alone;
(vii) **Workaholics**—Commonly considered to be workaholics.

Regarding Generation Y, we have identified the following characteristics (Cappi & Araújo, 2015; Limpinho, 2022):

(i) **Interconnectedness** — As they grew up in a very technological world, they have a high level of technological proficiency, easily using mobile phones, tablets, computers, and other devices as forms of communication, as well as quickly acquiring the knowledge to use new tools. Social networks also contribute with mechanisms for communicating and interacting with others, both professionally and personally; this is a generation that sustains a large part of its social relationships through interconnectivity;
(ii) **Individuality** — They are committed to their personal and professional development through training and continuous learning as a way of enhancing their skills and self-expression;
(iii) **Flexibility and Work–Life Balance** — Like their Generation X parents, flexibility, especially in terms of working hours, is valued here, and is even a mechanism for work–life balance;
(iv) **Diversity**—This is a heterogeneous generation marked by diversity of thought, sexual orientation, gender, ethnicity, and religion;
(v) **Competitiveness and Ambition** — Competition is valued against teamwork and collaboration, as this generation has strong ambitions for professional progression, often in short periods of time. As a result, they don't accept waiting a long time for a promotion and value constant feedback;
(vi) **Social Awareness** — Activism is a distinctive characteristic of many members of this generation, fighting for social and environmental causes is one of the distinctive characteristics of many members of this generation;

(vii) **Self-Confidence and Self-Esteem** — Are characteristics of this generation which leads them to believe in their professional progression and generates some discontent and dissatisfaction when their aspirations are not met;
(viii) **Rejection of Imposed Authority** — They don't easily accept imposed authority and tend to be less submissive to hierarchies, presumably because they are generally highly qualified individuals.

The systematisation of the characteristics identified above is shown in Table 1.

The literature has been abundant in studies that aim is to demonstrate the differences between the generations that currently make up the workforce, but there are also studies that suggest that the generations are more similar than different, and the differences are not significant (e.g., Badali, et al., 2022; Dick, 2019; Kelan, 2014; Kowske et al., 2010; Marques et al., 2023; Martin & Gentry, 2011; Mencl & Lester, 2014). A study conducted in Portugal (Ferreira, 2017) states that the results do not confirm generational differences in terms of the most valued aspects of work. For this author, the role of generational cuts is reductive when compared to individual development processes. Costanza et al. (2012) carried out a meta-analysis on studies related to generational differences and the results obtained do not support the hypothesis that there are systematic and substantive differences between generations. The slight differences obtained can be attributed to other variables, and not a generation. Kowske et al. (2010) go a step further by agreeing with the current that argues that generational differences could be renamed "generational similarities".

The study of employee motivation is fundamental for HRM, given the various challenges facing this area. Some studies have sought to understand which factors can contribute to employee motivation and retention (e.g., Badali et al., 2022; Ferreira, 2017; King et al., 2017; Marques et al., 2023).

Table 1 Generations X and Y characteristics

Generation X characteristics	Generation Y characteristics
Independence	Interconnectedness
Concern about self-esteem and self-confidence	High self-esteem and High self-confidence
Rejection of excessive supervision	Rejection of the imposed authority
Adapting to change and valuing upward mobility	Adapting to change and valuing upward mobility in a short space of time. Need for constant feedback
High technical proficiency	Sexual, ethnic, and religious diversity
Need a lot of information	Valuing training and constant learning
Individualism	Competitiveness but also cooperation
Workaholics	Valuing work–life balance

Source Adapted from and Araújo (2015), Limpinho (2022), Teixeira et al. (2014)

Badali et al. (2022) studied the moderating effect of Generations X, Y and Z on employee motivation and retention. They analysed factors such as retention, leadership, autonomy, corporate social responsibility, work–life balance, technology, and intrinsic motivation. They found differences and similarities between generations regarding the factors that contribute to retaining individuals from the various generations but did not find empirical support to sustain clear differences between generations. The authors indicated that leadership, but only from the perspective of transformational leadership is valued by all generations.

Marques et al. (2023) carried out a study to assess the factors that most contribute to motivating employees, emphasising talent management and rewards. They concluded that the companies studied do not have a formal talent management system and the rewards system of these organisations is essentially related to productivity bonuses. They also concluded that motivation is a determining factor in retaining workers and is influenced by access to training that is recognised as useful and by development opportunities, recognition, and career progression.

2.3 Strategies and Challenges of Human Resources Management for Generations X and Y

Studies have shown that a generation's work behaviour is influenced by its own values, attitudes, and characteristics (King et al., 2017). Age has been studied as a variable that generates greater diversity and different work behaviours (Veloso et al., 2016).

The development of a generational profile is susceptible to establishing what individuals of this generation want from work, the value and perception of the job (Tsaur & Yen, 2018); what type of work environment they want (Máynez-Guaderrama et al., 2023) what their preferences are for leadership styles (Bilge et al., 2021); and also have an influence on work–leisure conflict, satisfaction with leisure, psychological well-being, and job satisfaction (Bilge et al., 2021; Goh & Baum, 2021).

According to practitioners the generation-based work value differences are likely to impact most of the facets of people management such as recruitment, career development, compensation and benefits, training, and development, also leading to workplace conflicts (Parry & Urwin, 2011). Practitioners also suggest that if these differences are managed well, they can be a source of significant strengths and opportunities (Lancaster & Stillman, 2002).

The fact that organisations are composed of different generations is a challenge for organisations, particularly for managers and HRM (Pedro & Santos, 2023). It is vital to understand the values structure and underlying profile of each generation and the differences between these generations, if the managers want to develop and stimulate a working environment that promotes leadership, motivation, communication, and generational synergy (Smola & Sutton, 2002). In such a dynamic context, which is a

consequence of generational differences, it is very likely that no single management style can achieve desirable results (Urick, 2017) and that broader solutions must be found, geared towards the different needs of the different generations present in organisations (Santos & Pedro, 2020).

Meriac et al. (2010) reinforce this perspective by illustrating some studies that have advocated the need for different (human resources) practices that respond to the different generational cohorts (Millennials, Generation X, and Baby Boomers) in organisations, arguing that generational groups develop similarities in their attitudes and beliefs based on shared life experiences.

Some studies have examined the differences between generations, including between work values (Robbins, 2019; Ware, 2013); motivation (Lee et al., 2022); learning orientation, commitment and retention (D'Amato & Herzfeldt, 2008; Lee et al., 2022); personality traits (Dirk Stelling, 2023); beliefs about career success (Dries et al., 2008); and levels of creativity and innovation (Carney, 2009), with a significant differences between generations found in some of the studies.

Training

However very few studies (Urick, 2017) have closely examined potential differences in preferences for training and development between generations, with the objective to study how training and development practice might be adapted to suit the preferences of those who are to be trained.

The study conducted by Urick (2017) suggests that the analysis of generational trends finds expression in the technological differences between generations and recommend identifying and addressing the motivational needs of each generation and training each generation mindful of its learning styles.

This research shows that there may be different training-related preferences between generations, and offering a variety of formats responds to these preferences. Additionally shows that even though trends occur, each person within a generation is also an individual who might not fit their generation's overall characteristics preferences. Urick (2017) suggests that the optimum combination of different forms of training and development should be made, as a response to both employees that fit their generational characteristics preferences as well as those that do not.

It suggests that the optimum combination of different forms of training and development should be made in the light of trainees' preferences. Those "*preferences might be for technology-enabled and formal training, or a mixture of instructor-led and self-directed learning or in the case of self-employed, higher-level professionals perhaps largely self-directed and informal training making use of online facilities*" (Urick, 2017: 5).

In the likely event that one optimal combination of formats cannot be found for organisation, might allow employees to choose from several packages of training and development plans, choosing what was optimal for their career path. Team building should include intergenerational pairing based on complementary strengths. Finally, he recommends analysing the results of the training to determine whether this more personalised training style results in more effective training.

Regarding Generation Y, Eisner (2005) points out that it is advisable to meet the expectations of this generation's workers, especially in digital-based training programmes, for which work, and play are mixed and achievement and winning are important. Training for Generation Y workers should focus on strategic and advanced areas, involving them experientially, allowing for practice and providing a valuable reward at the end of training. This Generation no longer expects long-term rewards, as is the case with Generation X, but instead negotiates each new job looking for the best overall working environment, including opportunities for training and work–life balance.

Generation X demand training and want to learn everything. They give value to intensive learning because so that all their questions can be answered right away. Many Generation X individuals exhaust the learning opportunities within a few years, and they start to look for better career opportunities (Cordeniz, 2002).

Recruitment

Recruiting and retaining the best employees is an essential ingredient to organisational success. Generation Y is different from its predecessors in terms of work-related characteristics, which have implications for recruitment and retention. The policies and methods previously used to attract the best candidates from Generation X are likely to be relatively ineffective with Gen Y (Luscombe et al., 2013).

The technological advancements reshape R&S practices through a set of interconnected technological tools, processes, and practices that have given rise to recruitment, screening, and career management platforms, aptitude, personality and simulation tests, online candidate search systems, CV databases, and candidate attraction procedures (Derous & Fruyt, 2016).

E-recruitment as the practice of publishing job opportunities on databases, social networks and corporate websites is used today not only to attract highly qualified candidates, select suitable profiles and increase the efficiency of the recruitment and assessment process for both recruiters and candidates, but also because Generation Y is attracted to these recruitment practices through multimedia tools (such as mobile tests, video CVs, using LinkedIn as a recruitment platform, etc.) because they have grown up in the digital age and in a world full of information that allows them to be always connected. Generation Y also perceives that e-recruitment is influenced by their behaviour on social networks such as Facebook and LinkedIn, by the posts they make on these networks, which can influence the recruiter's perceptions (Bolton et al., 2012). E-recruitment may not be suitable for many Generation X individuals, and there may be a preference for face-to-face interviews rather than virtual ones, or who may prefer to be explained the application process by recruiters rather than by interactive software using artificial intelligence. Recruitment and Selection and its techniques should be aligned with the values and experiences of the candidates' generational profile in order to attract the interest of different generations.

Retention

Retention as a process in which employees receive support and encouragement to remain in within the same organisation for an extended period, or until the completion of a particular task (Das & Baruah, 2013) is fundamental to effective HRM.

Generation X prefers to engage in interesting and autonomous work and may remain at one workplace for a long period of time, enjoying a favourable work environment and valuing career progression (Goessling, 2017). However, Generation X not making career progression the central reason for staying in the organisation.

Generation Y prefers increasing extrinsic rewards (salaries and additional benefits), which is why they expect to stay in the same workplace (Twenge, 2010). The organisation can retain its Generation Y' employees, by providing these rewards as incentives.

Organisations should provide career counselling programmes for Generation Y employees to improve worker retention (Lowe et al., 2011) and promote good working conditions and a positive work environment for Generation X. Mentoring programmes are also critical to retain Generation Y, to seek advice, feedback, or guidance to achieve results in a more productive and satisfying way.

3 Research and Methodology

The study aims to understand which factors contribute to attracting and retaining Generation X and Generation Y individuals in organisations and carry out a comparative analysis of Generations X and Y of the differences and similarities.

The article presents a view of some of the results of quantitative study among a convenience sample addressed to Alumni participants (Generation X and Generation Y graduates in various academic fields) from a University of Applied Sciences in Portugal. For this reason, although the data provides a deeper understanding of Generation Y and X, it cannot be extrapolated (Hill & Hill, 2009).

The quantitative research was performed through an anonymous questionnaire survey. The questionnaires were distributed online form. The choice of this research tool allowed for inclusion of a wide sample of respondents. In our study, data collection obtained 421 valid responses from respondents, which represents the appropriate sample size for this study (Krejcie & Morgan, 1970). The data were collected within six weeks from 12 June 2023 until 23 July 2023.

This instrument was previously presented to the institution's Ethics Committee, which gave its positive opinion on the presentation and analysis of the data and on safeguarding the identity and sensitivity of the respondents.

We developed a questionnaire integrating the measurement scales of the research variables and questions related to the expectations and evaluation of the factors to attract Generation X and Generation Y into organisations. The questionnaire contains 14 questions, divided into 5 sections: Sociodemographic Characterisation, Work

Situation, and Job Satisfaction Factors such as: job contents, benefits and incentives, salary, work time, work environment, autonomy, flexibility, career progression, access to training, teamwork, relationship with colleagues, relationship with superiors, work–life balance, quality of managers, Life at work quality, Socially responsible company Feedback, and Company that encourages innovation. Finally, a section about Work Experience. These factors were theoretically supported by contributions in the reference literature that identifies employee motivation factors (e.g., Badalli et al., 2022; Limpinho, 2022; Marques et al., 2023; Teixeira et al., 2014).

The data collected was standardised and processed in a database, which involved creating some new variables through recoding (age group, academic degree, etc.).

All the assessments of data normality, reliability, and validity met the statistical requirements. Data processing was carried out using descriptive statistics, and association and correlation relationships between variables were calculated.

3.1 Participants

The questionnaire was applied, and 421 validated surveys were received, according to the demographic data in Tables 2, 3, and 4.

Table 2 shows the age of the respondents by age group and gender:

The majority of the women who took part in the study were in the 41–50 age bracket (43%), a figure very close to the 31–40 bracket (40%). The distribution of the other values is very residual. Majority of male participants are in the 31–40 age bracket, followed by the 18–30 bracket (24%) and the 51–60 bracket (11%). Although

Table 2 Demographic features (N = 421)

Age (years old)	Relative frequencies (%)		
	Female	Male	Total
18–30	9	24	16.5
31–40	40	42	41
41–50	43	21	32
51–60	6	11	8.5
>60	2	2	2

Table 3 Generation by gender (N = 421)

Gender	Relative frequencies (%)		
	Generation X	Generation Y	Total
Female	7	54	61
Male	8	31	39
Total	15	85	100

Table 4 Generation by academic qualification (N = 421)

Gender	Relative frequencies (%)			
	Academic qualification	Generation X	Generation Y	Total
Female	1st cycle degree	74	72	72
	Master degree	26	26	26
	Ph.D.	0	2	2
Male	1st cycle degree	70	76	74
	Master degree	27	23	24
	Ph.D.	3	2	2
Total	1st cycle degree	72	74	73
	Master degree	27	25	25
	Ph.D.	2	2	2

the men taking part in the study tend to be younger, the sample is very much concentrated around the 31–40 and 41–50 age groups, which means that the individuals are close in age and on the border between the two Generations. This situation may indicate some hybridity and dilution of results in terms of the characteristics reported in the literature for each of the Generations analysed.

As we can see, Table 3 analyses the distribution of the sample considering the gender, segmented according to Generations X and Y.

A total of 421 respondents were involved, composed of 164 (39%) male and 257 (61%) female. The average age is 35.52 years, with 16.5% between 23 and 30 years of age, 41% between 31 and 40 years of age, 32% between 41 and 50 years of age, 8.5% between 51 and 60 years of age, and 2% over 60 years old. Women are more represented in the 41–50 age group than men, with 43% and 21% respectively. The group with the most expression corresponds to those born between 1982 and 1992 and who "witnessed" the arrival and spread of the internet.

Generation X according to the generational cohorts established in this study corresponds to 15% of the participants (64) and Generation Y corresponds to a total of 85% (357). Women are more represented in the Y generational group than in the X generational group.

Table 4 shows the distribution of respondents according to generation, educational qualifications, and gender:

In terms of academic qualifications, 73% of respondents have a 1st cycle degree, while 25% have a master's degree or higher (25% with a master's degree and 2% with PhD). 26% of Generation X women have a 1st degree or higher, while men have a slightly higher percentage at 30%. In Generation Y, on the other hand, 28% of women have a 1st degree or higher, while men have a slightly lower percentage (25%).

We concluded that there were no significant differences in academic qualifications, either between generations or between genders.

4 Findings

In this section, we propose to present the main results of the study. We consider it relevant to present descriptive statistics that allow us to identify gender and intergenerational differences in terms of the participants' family and professional lives. We used correlational analysis to identify the most significant correlations between the study variables. We then present the factors that are most relevant in terms of attraction and retention, based on an analysis of the average, standard deviation, and variance.

4.1 Family, School, and Work Situation

The reliability test was assessed via Cronbach's alpha coefficient with a value of over 0.9 (0.967), for the 19 items, which means very high internal consistency (Pestana & Gageiro, 2014). The data obtained in this study were analysed by using the 29th version of the SPSS.

Table 5 shows the respondents' family situation in terms of "people you live with".

Shows that the majority (87.5%) of Generation X respondents live with their own families and considering the age group corresponding to this generation, these results are expected.

Generation Y participants have a more diversified distribution. 23% of Generation Y live with their parents, 14.6% live alone, and 59% live with their own family. The fact that some members of Generation Y are still very young, sometimes recent graduates, makes it understandable that more of them live with their parents.

Regarding the work situation, the results shown in Table 6 are similar between the two Generations. The most significant difference is that 11.2% of Generation Y work and study, while the figure for Generation X is 7.8%. But it is expected that the youngest people will be studying and working. This result has something connected with the younger population who are still studying for their master's degrees.

Table 5 Generations X and Y—"Who you live with"

Live with…	Relative frequencies (%)	
	Generation X	Generation Y
Alone	9.4	14.6
Only with their children	0.0	0.8
Boyfriend/girlfriend	0.0	2.2
Sharing a house with other people	0.0	0.3
Parents	3.1	23.0
Own family	87.5	59.1
Total	100	100

Table 6 Generations X and Y —work situation

Work situation	Relative frequencies (%)	
	Generation X	Generation Y
Is studying	0.0	2.0
Is working and studying	7.8	11.2
Is working	89.1	83.2
Unemployed	3.1	3.4
Total	100	100

Table 7 Generations X and Y—number of career Jobs

Number of career jobs	Relative frequencies (%)	
	Generation X	Generation Y
1	12.5	20.7
2–3	45.3	48.7
>= 4	42.2	30.5
Total	100	100

The Table 7 identifies the generational differences in terms of number of career jobs.

The study shows that most participants in the study have changed jobs between 2 and 3 times, and this trend is most evident in Generation Y, which represents almost half of the sample (48.7%).

Table 7 also shows that Generation Y has the highest number of individuals who have had only one job. On the other hand, it is in Generation X that there is a higher percentage of people who have had at least four jobs.

Table 8 analyses the number of times the participants changed jobs, taking gender into account.

Comparing male and female respondents in terms of the number of jobs they have had, during their professional career, there is almost no difference. Most respondents have had 2–3 professional experiences. Generation X has a higher incidence of individuals with 4 or more professional experiences. This is in line with what was said by Mencl and Lester (2014) about the fact that there are no substantial differences between Generations when it comes to the labour market.

Table 8 Gender—number of career Jobs

Number of career jobs	Relative frequencies (%)	
	Female	Male
1	19.46	19.51
2–3	48.25	48.17
>= 4	32.29	32.32
Total	100	100

Table 9 Generations X and Y—average length of stay in a job

Average length of stay in a job	Relative frequencies (%)	
	Generation X	Generation Y
1 year	6.3	17.6
2 years	1.6	19.0
3 years	7.8	17.6
>3 years	84	46
Total	100	100

Table 10 Gender—average length of stay in a job

Average length of stay in a job	Relative frequencies (%)	
	Female	Male
1 year	18.29	12.19
2 years	17.12	15.25
3 years	17.90	13.41
>3 years	46.69	59.15
Total	100	100

According to the results shown in Table 9, 42.2% of Generation X, changed jobs more than four times and 45.3% changed jobs between two and three times. Generation Y, composed of younger individuals, shows very high results in the 2–3 jobs and more than 4 jobs ranges, which is in line with the theoretical perspectives discussed above. Regarding the average number of times, they stay in a job, it is clear that Generation Y stays less time than Generation X, which reinforces the results of studies on generational differences (Cordeniz, 2002; Mencl & Lester, 2014).

Table 10 shows the results of the average time spent in a job and shows that women are the ones who change jobs the most, although with slight differences when compared to men.

Table 10 shows that women change the most and men the least. These results seem to indicate that it is men who value stability and safety the most in this study's sample.

4.2 Correlations

The Cronbach's alpha test on the 19 items of the scale that make up the information-gathering instrument produced very satisfactory results with $\alpha = 0.98$, indicating a high degree of reliability of the scale.

The general analysis of the correlations shows some relevant interconnections between the variables and the retention and attraction factors. We also analysed the statistically significant relationships between several factors.

Given that our sample did not meet normality criteria, Spearman's correlation was used. By analysing the correlations, it was possible to construct Table 11, with a set of correlations that were statistically significant to 0.01. We have highlighted all those that are higher than 0.8:

- Benefits * Incentives and salary (0.803);
- Work environment * Quality of life at work (0.818);
- Teamwork * Relations with colleagues (0.814);
- Teamwork * Relations with managers (0.819);
- Relationship with colleagues * Relationship with managers (0.841);
- Feedback * Company that encourages the innovation (0.834).

It is also important to underline the correlation between access to training and working hours (0.782) and innovation, although the correlation coefficient is less than 0.8.

The analysis highlights six factors that contribute to the satisfaction of individuals in organisations and which are related to:

(i) The work environment and quality of work–life,
(ii) Working Hours,
(iii) Remuneration, benefits, and rewards,
(iv) Relations between peers and hierarchical relations,
(v) Feedback and innovation,
(vi) Access to training.

It can be seen that working hours, working environment, and relationships with managers and colleagues are the factors that correlate most with other factors. Also noteworthy is the statistically significant relationship between feedback and companies that promoted innovation. This result emphasises the importance of feedback as a factor for improvement and motivation to innovate. This finding is worth highlighting given that the ability to innovate is an element of organisational competitiveness in contexts of continuous change and transformation, such as Industry 5.0.

Respondents were asked to indicate the importance of the factors presented below according to a Likert scale with six points (1–6) where 1 meant not at all important and 6 meant very important. The results are shown in Table 12.

The analysis makes possible to highlight a set of factors that are considered in this study to be the most important (average of 5 or more) for the workers who responded, and which we have listed in order of importance according to the average: work–Life Balance (Generation X 5,33; Generation Y 5,19), Autonomy (Generation X 5,21; Generation Y 5.11), Work environment (Generation X 5.20; Generation Y 5.13), Flexibility (Generation X 5.17; Generation Y 5.17), Working hours (Generation X 5.12; Generation Y, 5.04), Life at work quality (Generation X 5.15; Generation Y, 5.03), and Job Contents (Generation X 5.00; Generation Y 5.17).

We also found that the differences between generations are not very significant, except for the task content item which is more valued by Generation Y, and the flexibility item which is equally valued by both generations. The other items analysed are more valued by Generation X, although with slight differences.

Table 11 Spearman correlations by generations

	X (1960–1979)	Y (1980–2000)
N	64	357
Alpha Cronbach (19 itens)	0.978	0.964
Correlations	Correlation coefficient	
Age/relationship with superiors	−0.251*	
Benefits and incentives/salary	**0.803****	0.766**
Salary/recognition	0.740**	
Salary/career progression	0.711**	
Working hours/work–life balance		0.758**
Work environment/Autonomy	0.706**	
Work environment/working hours	0.708**	
Work environment/managers quality	0.744**	
Work environment/life at work quality	**0.818****	
Autonomy/work environment	0.706**	
Autonomy/life at work quality	0.785**	
Career progression/recognition	0.760**	0.773**
Recognition/managers quality		0.714**
recognition/life–work quality		0.717**
Access to training/working hours	0.782**	
Access to training/company that encourages innovation	0.717**	
Working hours/relationship with colleagues	**0.834****	
Working hours/relationship with superior	**0.819****	
Working hours/life at work quality	0.793**	
Working hours/empresa socialmente responsável	0.715**	
Working hours/feedback	0.782**	
Working hours/company that encourages innovation	0.707**	
Relationship with colleagues/Relationship with superior	**0.841****	0.750**
Relationship with colleagues/life at work quality	0.735**	
Relationship with superior/life at work quality	0.758**	
Managers quality/life at work quality	0.790**	0.767**
Managers quality/feedback		0.713**
Life at work quality/feedback		0.713**
work–life balance/ life at work quality		0.710**
Socially responsible company/feedback	0.760**	0.710**
Socially responsible company/company that encourages innovation	0.701**	0.702**
Feedback/company that encourages innovation	**0.834****	0.743**

Legend *<0.05; **<0.01

Table 12 Means, standard deviations, and variance for the importance items by generation

Variable	Generation X (n = 64)			Generation Y (n = 357)			Dif.—Avg.
	Avg.	SD	Var.	Avg.	SD	Var.	
Job contents	**5.00**	**1.24**	**1.54**	**5.17**	**0.95**	**0.91**	**−0.17**
Benefits and incentives	4.86	1.29	1.66	4.82	1.31	1.71	0.04
Salary	4.91	1.31	1.71	4.87	1.33	1.76	0.04
Working hours	**5.12**	**1.26**	**1.59**	**5.04**	**1.19**	**1.41**	**0.08**
Work environment	**5.20**	**1.19**	**1.42**	**5.13**	**1.06**	**1.12**	**0.06**
Autonomy	**5.21**	**1.18**	**1.40**	**5.11**	**0.97**	**0.93**	**0.10**
Flexibility	**5.17**	**1.21**	**1.46**	**5.17**	**1.10**	**1.20**	**−0.01**
Recognition	5.03	1.32	1.75	4.93	1.29	1.65	0.10
Career progression	4.89	1.37	1.88	4.74	1.44	2.08	0.15
Access to training	4.89	1.30	1.70	4.68	1.27	1.62	0.21
Teamwork	4.80	1.28	1.63	4.76	1.22	1.49	0.04
Relationship with colleagues	5.12	1.21	1.46	4.97	1.04	1.08	0.15
Relationship with superior	5.09	1.25	1.56	4.99	1.05	1.10	0.10
Work–life balance	**5.33**	**1.28**	**1.64**	**5.19**	**1.19**	**1.42**	**0.14**
Quality of managers	5.05	1.33	1.76	4.80	1.27	1.62	0.24
Life at work quality	**5.15**	**1.19**	**1.42**	**5.03**	**1.16**	**1.34**	**0.12**
Socially responsible company	4.70	1.28	1.63	4.40	1.38	1.90	0.30
Feedback	4.82	1.24	1.53	4.67	1.22	1.48	0.14
Company that encourages innovation	4.82	1.32	1.75	4.56	1.35	1.83	0.26

5 Discussion and Conclusion

In this section, we analyse the results obtained to answer our objective. The analysis was carried out to understand the organisational factors that contribute to attracting and retaining Generation X and Generation Y individuals in the labour market.

This generational approach is supported by the reference literature, which argues that it is possible to find some homogeneity of perceptions and behaviours between individuals who were born in a certain previously defined period. This homogeneity systems result from the sharing of remarkable and common events that affected these individuals and moulded their way of seeing the world (Hess & Jepsen, 2009). It is also supported by studies that emphasise the presence of more similarities than differences. The similarities or slight differences obtained, on the other hand, can be attributed according to some authors to other variables, and are not associated with generation (Costanza et al., 2012).

There is also no consensus in the literature regarding the beginning and end of a generation. We take the perspective of the generational cohorts of Cannon and Kendig (2018) in which Generation X includes individuals born between 1960 and 1979 and Generation Y includes individuals born between 1980 and 2000 (Barriopedro et al., 2018; Prakash & Tiwari, 2021; Souto, 2018; Stewart, 2017).

We can conclude that intergenerational studies have the potential to contribute to the study of labour relations in the current context of Industry 5.0, as well as to the study of HRM practices that best fit with these new contexts.

It also makes it possible to establish an integrated approach with other factors that contribute to adapting management policies or practices to the diversity of human capital that currently exists. Experts suggest that managers apply messages and strategies deliberately tailored to the characteristics of each of the generations.

These specificities of the different needs raised by the different generations in the same labour context lead us to move forward a new perspective on HRM, already put forward by some authors (e.g., Skýpalová et al., 2023), which is the individual perspective.

Age, gender, academic and cultural background, values, and possibly interests make each worker unique and must be managed accordingly. The complexity of Industry/Globalisation 5.0 manifests itself for workers as a world of work with unlimited possibilities, especially for the younger generations.

The results of this study were obtained by applying a questionnaire to Generation X and Generation Y individuals, who have in common the fact that they are graduates of a higher education institution in Portugal. The analysis made it possible to identify some factors that can attract and retain individuals.

The results corroborate some trends identified in the literature that it is not possible to identify very relevant differences between Generations X and Y, which may be linked to the fact that the convenience sample was only made up of graduates from a higher education institution. These results are in line with studies conducted by Dick (2019), Kowske et al., (2010), Mencl and Lester (2014), Martin and Gentry (2011). So, there are more aspects that unite than separate the generations.

The nature of the sample certainly contributed to these results. It should be remembered that we used a convenience sample which reveals some heterogeneity in terms of generational representation. Generation Y is over-represented (85% of respondents) compared to Generation X (15% of respondents). This blurring of the boundaries in terms of age has contributed to the drawing of a sample in which the characteristics that distinguish one Generation from the other are diluted, leading to a certain homogeneity of results.

Nevertheless, we believe that these results contribute to adding knowledge about the factors that motivate individuals in the labour market, especially if we consider the age groups between 31 and 50, which are the most represented in our sample.

The main results in response to the objective of understanding which factors contribute to attracting and retaining workers, as seen through correlational analysis, allow us to identify a set of relationships that we can systematise and hierarchise into 4 elements that are highly valued: (i) The work environment and quality of life at work; (ii) Remuneration, benefits, and rewards; (iii) Relations between peers and

hierarchical relations; (iv) Feedback and innovation. It can be inferred that the work environment and quality of life are seen as a broader umbrella that is materialised from factors related to working time, pay and rewards, relationships and communication, and access to training.

The descriptive statistics corroborate the results obtained by looking at the factors that were most valued by the respondents and considered very important or quite important: Work–Life Balance, Autonomy Work environment, Flexibility, Work time, Life at work quality, and Job Contents.

These results are consistent with the correlation analysis and with the reference literature, taking into account a wide range of authors who support the importance of motivation for employee retention (e.g., Badali et al., 2022; Marques et al., 2023; Limpinho, 2022; Teixeira 2014).

HRM has never been faced with such demanding challenges, due to the gradual change in traditional power relations, demographic growth, increasingly dynamic work contexts, and the heterogeneity of interests and expectations (Urick, 2017). Therefore a successful multigenerational workplace understands the dynamics and challenges of generational differences, if they exist, enabling effective communication and knowledge transfer between the generations.

The analysis made it possible to identify some limitations in the constitution of the sample, with a predominance of females and Generation Y individuals.

For this reason, it is considered that the study should be applied to more homogeneous samples in order to obtain results that make it possible to isolate generation as an independent variable. It is also important to carry out a comparative analysis of an international nature, allowing us to diversify the results from other cultures and labour markets with different characteristics to the Portuguese labour market, in order to understand the weight of generational belonging in broader contexts.

Carrying out new studies will also make it possible to consolidate the information collection tool developed by the research team. We believe that a larger sample with a more equitable representation of the generations being analysed and which also includes an international dimension should make it possible to carry out a more in-depth analysis of the effect of the generations on individuals' work expectations. Finally, in a context of change, with the emergence of artificial intelligence and Industry 5.0, it will be particularly important to have an idea of the processes that lead to attracting and retaining talent in this sample.

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Talent Management and Smart Organizations: A Strategic Symphony

João Lima and Carolina Feliciana Machado

Abstract In the dynamic context of contemporary business, talent management emerges as the fundamental pillar for the success of intelligent organizations. This chapter explores the vital importance of attracting, developing, and retaining exceptional talent as an essential strategy for driving innovation, adaptability, and organizational resilience. By recognizing employees as strategic assets, intelligent organizations invest not only in practices but in a philosophy that promotes excellence and sustainable success in the complex business scenario of the times we are going through.

Keywords Talent management · Smart organizations · Change · Competitive advantage

1 Introduction

In a constantly evolving business scenario, intelligent organizations emerge as protagonists in the search for excellence and continuous adaptation. In this context, talent management plays a crucial role, acting as the driving force that drives growth and innovation.

Over the last few years, we have observed the growing and permanent mutation of today's world, due to globalization, the emergence of new technologies, that is, the revolution of the digital era, and the evolution of markets. Faced with these changes, organizations need to look for effective answers. In this way, investing in human capital proves to be one of the solutions that companies most resort to, given that people are the main asset of an organization, contributing to differentiation from

J. Lima · C. F. Machado (✉)
School of Economics and Management, University of Minho, Braga, Portugal
e-mail: carolina@eeg.uminho.pt

C. F. Machado
Interdisciplinary Centre of Social Sciences (CICS.NOVA.UMinho), University of Minho, Braga, Portugal

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other competing companies. In this sense, it is essential nowadays that companies are able to attract, develop, and retain talent.

Talent management is a priority for companies and has become increasingly important in terms of organizational management policies and practices. Therefore, organizations must have the ability to attract talent, through the dissemination of their organizational culture, their mission, vision, and values. However, attracting talent alone is not enough for companies to achieve a competitive advantage. It is important to retain key talent within the company, developing a set of procedures, policies, and management instruments that promote a climate of well-being and stability in the workplace, with a view to meeting the possible needs of their talents.

Thus, talent management is often seen as a strategy that is linked to the needs of a company, with the purpose of retaining the human resources that have the greatest talent (Capelli, 2009).

Aware of the importance that talents and talent management assume in the pursuit of increasingly innovative and intelligent organizations, this chapter's main purpose is to reinforce and expand the field of knowledge that talent management presents within smart organizations, more than solving any problem on the topic under analysis. In this way, a brief literature review will be carried out on this issue under study.

2 Talent Management

Faced with increasing technological modernization and the resulting speed in terms of information sharing, new challenges arise that organizations must face, such as changes in the structure of the labor market, structural changes that occur within a given organization and the emergence of new organizations. In this way, human resources management has the responsibility to adopt an adaptability stance, with the aim of becoming more efficient and effective compared to the competition with regard to the flow of talent.

According to Klein (1998), people are primarily responsible for ensuring the success or failure of an organization, since they are, through their different characteristics, skills, knowledge, experiences, values, attitudes, and behaviors, that form the intellectual capital, ultimately dictating competitive advantage in the market. Therefore, people are seen as the main strategic factor of an organization, given that the success of a company depends solely and exclusively on human capital.

For Gebelein (2006), organizations, in most cases, recognize that no matter how much they have a clear and well-defined strategy, without talent (human capital) they cannot overcome obstacles and face new challenges with due success. In this sense, it becomes essential for companies to attract and retain human capital in order to differentiate themselves from other companies in the market, which leads to the practice of talent management policies (Cook, 2010).

When it comes to the definition of talent, it has multiple definitions, with several researchers studying this topic, and there is no common and consensual definition. Several authors mention different definitions of this concept, and sometimes these

definitions prove to be contradictory. For example, if an employee has skills that others do not demonstrate and has the ability to develop them, the question arises as to whether they are a talent or not. Talent is also associated with the organizational context in which it operates, that is, in a given organization the employee is recognized as talented, since they have certain skills, abilities, and knowledge that others do not have, however, in another organization, the same employee may not be considered a talent, as there may be employees with higher skills (Gallardo-Gallardo et al., 2013).

According to Williams (2000), talent is certain people who recurrently demonstrate extraordinary ability in a wide range of activities, tasks, and situations, or within a specialized field or who more consistently demonstrate high competence in different areas of activity that have yet to be tested. Therefore, this concept is understood as a group of selected employees, that is, those who are at the top in terms of capacity, competence, and performance, rather than the entire workforce (Stahl et al., 2007).

Tansley et al. (2007) argue that talent is made up of individuals who eventually leave their mark of difference on the overall performance of an organization, whether through their contribution in the short term or long term, clearly showing their high levels of potential and capacity.

According to Michaels et al. (2002), talent consists of a set of characteristics and capabilities that a person presents, such as their abilities, knowledge, skills, experience, intelligence, behaviors, attitudes, and skills, as well as the learning and development capacity. Therefore, this is contextual, since an employee considered talented reveals a greater commitment to the organization and uses their abilities to obtain better results (Jericó, 2001).

Ulrich (2014) highlights that talent is dependent on the coexistence of three aspects, defining the theory of the "three C's", composed of Competence, Commitment, and Contribution. Therefore, the existence of these components in the employee must be observed to be considered a talent.

Nowadays, organizations are increasingly looking for employees with a profile, with a wide range of knowledge, skills, and behaviors that are fundamental to success in a given activity. Given the continuous competitiveness that is felt in the market, companies are looking for employees who make a difference. Therefore, within the organization, people who have high potential and talent usually prove to be indispensable. Therefore, having talent consists of having employees who have the necessary characteristics to occupy a desired position, as well as the main requirements with a view to achieving the objectives of a given organization. Therefore, in order to attract the best talent, the organization must present a strong, differentiating, positive, and reputable brand so that it is appealing and attractive for recruiting the best candidates (Capelli, 2009).

Talent Management is one of the most important and debated issues in the area of human resources management and is often seen as one of the biggest problems and challenges in several organizations (Valverde et al., 2013).

Capelli (2009) states that talent management is a strategy that is framed according to the needs of a given organization, with the objective of retaining the most talented human resources, taking on an enormous challenge, that is, recruiting individuals

with the characteristics and right skills for the job requirements. Therefore, talent management is a concept that encompasses a set of strategies and procedures aimed at attracting, identifying, developing, and retaining talent, which proves to be the main factor contributing value to the organization and, consequently, allows it to differentiate itself in the market (Tansley, et al., 2007).

In the first phase, it is essential to attract talents that have differentiating characteristics for the organization, so that they are seen as an added value. Next, one must select a profile that stands out for its difference, as well as promote greater involvement and development of talents within the organization. Finally, it is necessary to retain talent, with the aim of reducing team turnover and ensuring that training and development translate into increased competitive advantage for the organization.

2.1 Talent Attraction

In recent years, attracting talent has been an increasingly relevant factor for an organization when it comes to building organizational capabilities with the aim of maintaining competitiveness. In this sense, organizations have the need to attract talent, as they are fundamental to the success of organizations (Song et al., 2010).

According to Dijk (2008), for the organization to efficiently attract the best talent, it must develop a recruitment and selection process, and there must be a balance between what the organization wants and what the candidates have to offer.

In this sense, the first phase to be carried out in recruitment involves identifying the skills, competencies, experiences, abilities, and knowledge that the candidate presents, as well as checking whether they are compatible with what is required for the role to be performed. The organization must define in advance the ideal type of profile to recruit to fill the position, since talent is contextual. Furthermore, it needs to observe how the candidate contributes, so that the organization can obtain a competitive advantage (Dijk, 2008).

That said, in order to attract top talent, companies need to convey a good image, and, if possible, be duly recognized in the market as a result of their success.

2.2 Retaining Talent

In addition to attracting talent, companies must increasingly focus on retaining talent, in order to secure their main talents, thus increasing their competitive advantage. In this sense, it is crucial that the human resources management department develops certain procedures, instruments, and management mechanisms that make it possible to generate a climate of harmony and stability in the workplace, thus managing to meet the needs of talents.

According to Martins and Ohe (2002), talent retention consists of securing key talents, with the main objective of achieving advantages for having them and for them to grow and develop in the course of carrying out their duties.

James and Mathew (2012), with the purpose of finding the best alternative to retain employees, state that the organization must understand, together with them, what they want in the future and whether this will happen in the organization, providing some incentives, as each employee has different personalities and characteristics that the organization must understand, making them feel motivated, fundamental and valuable. Furthermore, organizations need to put into practice a set of policies and practices inherent to human resources management, to more effectively understand the possible needs of their employees and create efficient strategies. Thus, the way talents are managed directly and/or indirectly affects performance at an organizational level (Torrington et al., 2011).

Therefore, some authors argue that organizations must adopt certain strategies in order to retain their main talents and thus maintain their competitive advantage. In this sense, one of the talent retention strategies is related to norms, values, and incentives, as the organization provides symbolic "gestures" to its employees, giving them due recognition (Ortlied & Sieben, 2012).

Yamamoto (2011) states that one of the strategies for retaining employees involves balancing professional and personal life. Therefore, with the aim of promoting this balance, companies have adopted different measures, such as: shortening working hours, granting subsidies, more flexible working hours, parental leave, and the existence of a daycare center in the workplace. The implementation of these practices makes it possible to increase levels of satisfaction, employee motivation, and, fundamentally, well-being, whether at a professional or family level. Additionally, Hagel and Miller (2011) add that the attribution of good benefits, respect, recognition, and an excellent and stable relationship with managers are factors that interest and captivate employees and, in this way, allow their retention in the organization.

In short, it is up to companies to define measures and practices that they consider relevant for retaining their main talents, also leaving to the discretion some measures that fit the needs that each person presents.

3 Talent Management: The Challenge

Talent Management encompasses a set of practices associated with attracting, developing, and retaining people who leave their mark on an organization. However, nowadays it is still possible to observe that there are companies that still do not attach due importance to these practices, given that it is necessary to compare talent management practices with the context of each organization, that is, the sector of activity that the company is included. In this sense, this practice only makes sense in organizations that have qualified employees.

According to the study "Rewriting the rules for the digital age" carried out by Deloitte (2017), organizations were challenged to think about organizational structure, talent management, and human resources strategies, with the purpose of being able to keep up with successive technological innovations. More than 10,000 human resources leaders participated in this study, spread across 140 countries, with only 35% of human resources professionals having the capabilities to deal with the eventual revolution of the digital world.

With regard to talent management, participants claim attracting talent as one of the main challenges that organizations face, with 81% of the organizations considering it a "very important" or "important" factor. Although the study shows that cognitive technologies have contributed to attracting talent to the digital world, companies do not provide a differentiating experience for employees, with only 22% of participants considering their companies as "excellent" Therefore, through this study carried out by Deloitte, it is possible to conclude that more and more organizations are eliminating systems implemented in the past, being able to prepare their employees for the digital revolution, and answering efficiently and effectively to the numerous challenges caused by constant technological change.

Having said this, it becomes increasingly pertinent to value human capital, not only through monetary benefits, but fundamentally, by giving it due recognition. Communication, informal relationships, flexible working hours, carrying out after-work activities, granting incentives, and, above all, knowing how to listen to employees are some practices that organizations must rethink, in order to achieve success. In other words, the challenge in terms of talent management is to properly value people.

4 Talent Management in Smart Organizations

From all the above, it follows that, in a world characterized by deep transformations and increasingly accentuated and constantly evolving levels of competitiveness, smart organizations play a key role in achieving the desired levels of excellence and continuous adaptation. Performing, as we have just seen, talent management, a critical role as a driver of growth, creativity and innovation, characteristic of smart organizations, the relationship established between them plays an important role in achieving flexibility and proactivity so necessary in our days. Indeed, the potential that talent management has in building increasingly smart organizations is enormous, namely.

4.1 In Identifying and Attracting Talent

Smart organizations understand the importance of building dynamic and diverse teams. Talent management in this context goes beyond simple hiring. It involves proactively identifying individuals with unique skills and an innovative mindset.

These organizations seek not just to fill positions, but to shape a cohesive group of professionals who add value and propel the company to the forefront of the market (Gilch & Sieweke, 2021; Guerra et al., 2023).

4.2 In Continuous Development and Organizational Learning

Talent management in smart organizations transcends the initial recruitment phase. It embraces the philosophy of continuous development, recognizing that learning is a journey, not a destination. Smart organizations invest in training programs that enable their employees to adapt to new technologies, methodologies, and market challenges. This approach not only increases operational efficiency but also creates an environment conducive to innovation (Gold & Garad, 2019; Saputra, 2020).

4.3 In Organizational Culture and Engagement

Talent management in smart organizations is intrinsically linked to corporate culture. These companies cultivate an environment where creativity is valued, mistakes are seen as learning opportunities, and collaboration is encouraged. Through talent management practices focused on creating a positive culture, smart organizations are able to attract and retain the most qualified professionals, promoting a high level of engagement (Aboseif, 2021).

4.4 In Agile Adaptation and Rapid Answer to Changes

Agility is a core characteristic of smart organizations, and talent management plays a vital role in this regard. The ability to quickly identify, develop, and position the right talent is crucial to efficiently answer to market changes. Agile talent management enables smart organizations to adjust their teams according to evolving demands, staying at the forefront of innovation and competitiveness (Saputra, 2020).

In short, talent management and smart organizations form a strategic synergy. While smart organizations create the enabling environment for innovation and adaptability, talent management provides the key pieces that drive this machine of excellence. Continuous investment in identifying, developing, and retaining talent is therefore a cornerstone for organizations that aspire to not just survive, but thrive in a dynamic business world.

5 Final Remarks

Nowadays, we live in an era of sharing information as a result of recurring technological innovations, in which numerous challenges emerge that companies need to face in order to be able to keep up with the constant evolution of the market, and proactively anticipate constant changes.

In this way, the human resources area reveals itself as one of the key areas within a company, as it plays a crucial role in terms of adjustment, flexibility, and adaptability. Thus, people reveal themselves as the main factors that influence, directly or indirectly, the success or failure of the organization, as they are the ones who end up dictating the company's differentiation in the market (Klein, 1998).

Talent corresponds to a person who presents certain characteristics, personal and technical, that allow them to differentiate themselves from others, that is, they are people who leave their mark on the overall performance of the organization, leading to its success.

According to Tansley et al. (2007), talent management translates into a practice that encompasses a range of strategies, procedures, and mechanisms that allow attracting, identifying, developing, and retaining talents, which are assumed to be the main key elements for the construction and creation of value to the organization. In this way, talent management consists of developing human resources policies that make it possible to select, attract, retain, value, and develop people.

In short, talent management emerges as the solid foundation on which smart organizations build their sustainable success. As the dynamics of the business environment evolve, the ability to attract, develop, and retain exceptional talent becomes more crucial than ever. By recognizing that employees are strategic assets, smart organizations invest in creating a culture that nurtures individual and collective growth. This approach not only drives innovation and adaptability but also strengthens organizational resilience in the face of ever-changing challenges. Therefore, talent management is not just a practice, but a philosophy that drives organizations toward excellence and lasting success in the dynamic business landscape of the twenty-first century.

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