INDUSTRY 5.0 CONCEPTS AND COMPONENTS: A SCOPING LITERATURE REVIEW

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ABSTRACT

The term "Industry 5.0" was coined to represent a new phase of industrialisation. It builds on the technological advances of Industry 4.0, with a stronger focus on human centricity, sustainability, resilience, personalisation and customisation, and bioeconomy. Through human-machine collaboration, it is shifting the focus from economic value to societal value and well-being. A scoping literature review was conducted to explore existing studies on the Industry 5.0 frameworks. The findings reveal key concepts of Industry 5.0 and the key components that drive these components such as Cobots, AI, Digital Twins, Internet of Things, Big Data, Mixed realities, and Blockchain. The study's implications highlight the need for organisations to integrate these frameworks to enhance productivity and sustainability. This review offers valuable insights for practitioners and policymakers aiming to navigate the transition towards Industry 5.0.

Keywords: industry 5.0, human-centric, resilience, sustainability, scoping literature review, framework

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1 INTRODUCTION

There have been numerous industrial revolutions, from the mechanisation of production and steam power during the First Industrial Revolution to the ecosystem of ideas and technologies such as the Internet of Things (IoT) and the Cyber-Physical System (CPS) in Industry 4.0 [1]. However, as with any industrial revolution, it has a few shortcomings. Industry 4.0 lacked a strong emphasis on human interaction and collaboration, sustainable and ethical practices, and a beneficial drive for business and social success [2] [1]. These shortcomings paved the way for the emergence of Industry 5.0.

The term "Industry 5.0" was coined by the European Commission to represent a new phase of industrialisation [3]. It builds on the technological advancements of Industry 4.0, with a stronger focus on human-machine collaboration, customisation, innovation, resilience and sustainability, shifting the focus from economic value to social value and well-being [4]. It places the well-being of the industry worker at the centre of focus and emphasises the collaboration of human skills such as creativity, decision-making, and complex problem-solving with advanced technologies [1].

As this concept is still emerging, there is a unique opportunity to explore what the key concepts and components of the Industry 5.0 framework consist of. Most existing papers focus on specific scenarios or address only one or two elements of Industry 5.0. Therefore, this study plans to investigate the available literature on the general frameworks and elements of Industry 5.0 to assist organisations in implementing Industry 5.0.

It is important to clarify the use of frameworks and models. According to Difference Between [5], a framework provides an overall structure and shows the relationship between key different elements. It can help to organise and structure concepts and theories. A model is typically more prescriptive and detailed and aims to achieve a specific outcome [6].

In summary, while both frameworks and models are used to structure and organise knowledge, frameworks are more general and descriptive, focussing on the relationships between concepts, whereas models are more specific and detailed, aiming to explain or predict specific behaviours or outcomes. Therefore, a framework is best suited to the nature of the study to provide a general knowledge structure of Industry 5.0.

2 METHODOLOGY

A scoping review is the optimal methodology for this investigation due to the broad nature of the research questions [7]. It excels at mapping existing frameworks, clarifying key concepts, and identifying knowledge gaps – ideal for exploring Industry 5.0 frameworks.

The review will follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines and protocol. The protocol provides the plan for the scoping review and is important in limiting the occurrence of reporting bias. After creating the detailed protocol, the eligibility criteria for selecting studies or evidence sources are clearly defined. The review identifies and searches relevant databases and search engines to retrieve studies or evidence.

A search strategy is formulated to identify relevant studies, and a systematic process is used to select sources based on eligibility criteria. Data from the selected sources are extracted and organised through a charting process. The findings of individual sources are synthesised to identify common themes, patterns, or gaps in the literature.

The general results of the findings, common themes, and trends are discussed. The review concludes with a summary of the evidence, a discussion of limitations and implications for practice, policy, or future research, along with any recommendations. Finally, the resources allocated and the role of the funders are described.

Industry 5.0, the next iteration of industrial automation, emphasises a human-centred approach alongside the technological advances of Industry 4.0. The objective is to identify key elements in the new industrial revolution through the following research questions.

- **RQ 1: What are the key concepts in the Industry 5.0 frameworks?**

  Concepts are the higher-level ideas and theories that underpin the Industry 5.0 paradigm.

- **RQ 2: What are the key components of the Industry 5.0 frameworks?**

  Components are the specific technologies, systems, and approaches that make up the Industry 5.0 framework.

Through this investigation, we can establish a foundation for future Industry 5.0 frameworks, ensuring that they provide all the necessary guidance for successful industry-wide adoption. The following inclusion and exclusion criteria are established as part of the protocol.

Table 1: Inclusion & Exclusion Criteria

PRISMA Phase	Type of the criteria	Description of the criteria
Identification	Inclusion	Publication year > 2016
		Title, abstracts, or keywords containing terms: (“Industry 5.0” or “Fifth industrial revolution” or “5th industrial revolution”) and “manufacturing”
	Exclusion	Duplicated Articles
		Articles not published in English
Screening	Inclusion	Industry 5.0 concepts or components are the main or one of several topics that are reviewed, surveyed, or discussed.
	Exclusion	Articles out of the scope based on titles and abstract assessment
		Studies solely focused on Industry 4.0 or earlier industrial revolutions (unless explicitly compared to Industry 5.0)
		Full text not available

The following engineering-related databases are used: ScienceDirect, Scopus, IEEE Xplore, Web of Science, and Google Scholar. The keywords used in the search strategy are shown in Table 2. To limit the number of studies relevant to the study topic, no synonyms for ‘Framework’ are used in the search strategy.

Table 2: Keywords for Search Strategy

Keywords	Synonyms
Industry 5.0	'Fifth Industrial Revolution', '5IR', ‘5th Industrial Revolution’
Framework	n/a

3 RESULTS

The search strategies were drafted by the authors and further refined. The final search strategy is found in the table below, conducted on 18 May 2024.

Table 3: Search terms and results

Search terms and database	Science Direct	Scopus	IEEE Xplore	Web of Science	Google Scholar	Total
("industry 5.0" OR "fifth industrial revolution" OR "5th industrial revolution" OR 5IR) AND (framework)	96	447	174	216	71	**1004**

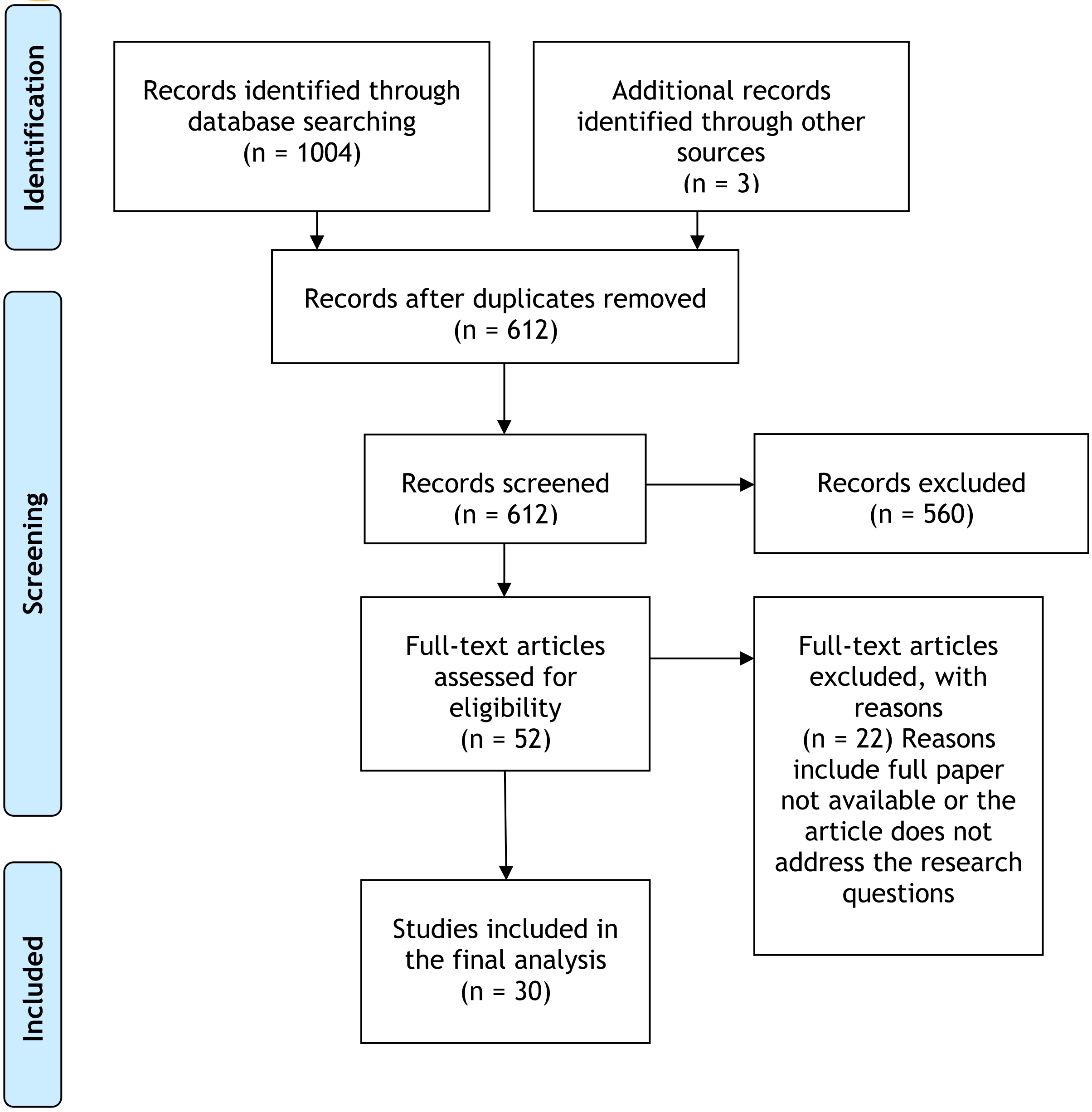
Search terms were used to search the title, abstract and keywords. However, since Google Scholar is a search engine, not a database, to limit the number of articles, only keywords were searched. Other sources include publications by the European Commission since they are a key driver and initiator of this transition.

The final search results were exported to Rayyan, a web application designed to organise, manage and facilitate the screening process. Based on the search, 1008 resources were gathered from 5 databases. After the duplicates were removed, a total of 612 citations were identified from searches of electronic databases and review article references. Based on the research protocol used to perform an initial screening, 560 were excluded, with 52 full-text articles to be retrieved and evaluated for eligibility and to ensure they directly address the research questions and objectives and provide relevant information about the industry 5.0 frameworks.

Of these, 22 were excluded for the following reasons:

- Unable to retrieve the full article.
- Focus on a very specific application of a technology.
- Industry 5.0 is only used as a reference and is not discussed in the paper.
- Focus only on challenges, opportunities, advantages, disadvantages or risks.
- Focus only on industry 4.0 technology frameworks.

The remaining 30 studies were considered eligible for this review.



3.1 RQ 1: What are the key concepts in the Industry 5.0 frameworks?

Figure 1 shows the most common to least discussed concepts in the 30 included articles. Each of these concepts will be discussed individually to understand the definition and application.

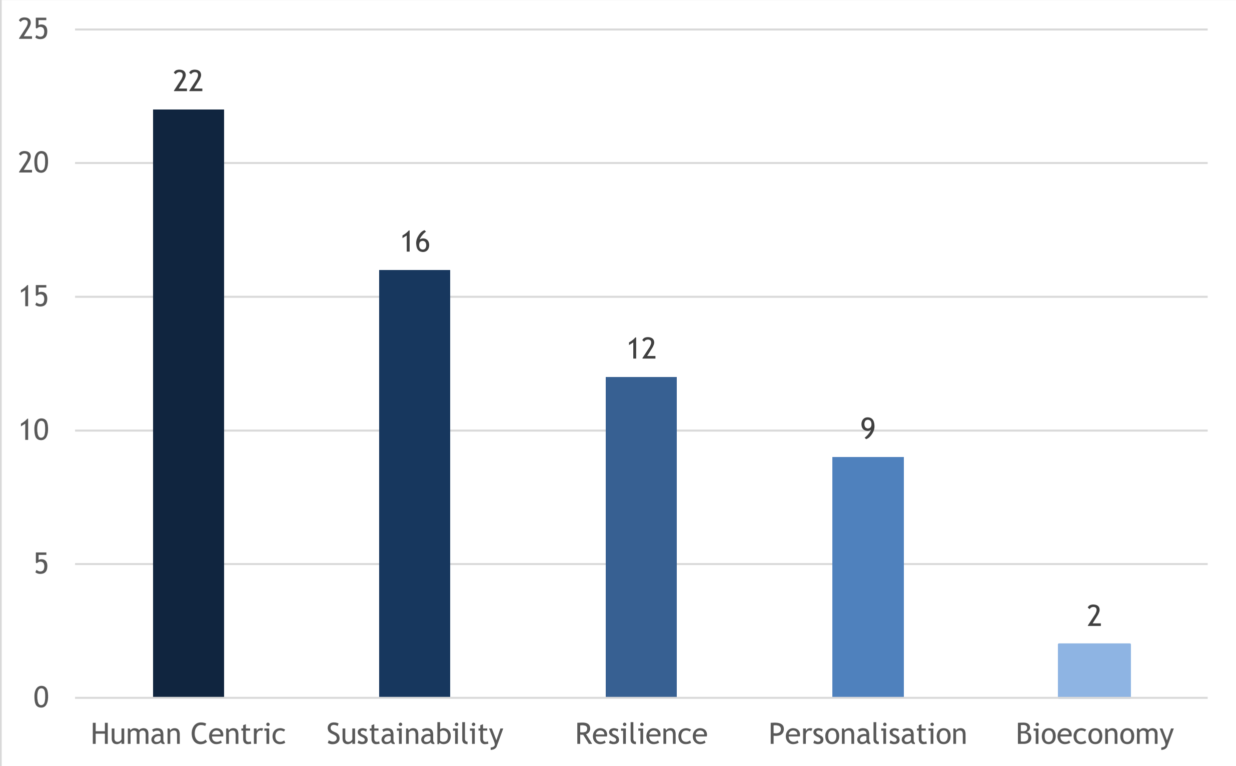


Figure 1: Number of articles discussing Industry 5.0 Concepts

3.1.1 Human-centric design

The authors emphasise that technology is not a replacement for humans, but a collaboration between people and machines to create more value-added for customers [8], [9]. It enhances their role in manufacturing by placing more importance on human intelligence and improvement of quality [10]. Industry 5.0 will eliminate monotonous and tedious tasks and pave the way for curiosity, empathy, creativity, and judgment [8], [11]. Humans will take on greater responsibility and increased supervision of systems [11]. Therefore it is imperative to hire the right people with the right skills to work safely alongside machines [12].The goal is to enhance workplace safety, minimise errors, and increase productivity through human-machine interaction [13].

Human centricity focuses on improving physical and mental well-being and viewing humans as assets. This includes incorporating principles such as autonomy, development, and psychological safety [14]. The 5C human-machine relations framework is introduced to implement the principles of coexistence, cooperation, collaboration, compassion, and coevolution [15]. A human-centric interaction model is created that consists of three elements: 1) human-machine understanding (2) human-machine collaborative intelligence, and (3) human-machine communication [15].

Technology will be used to benefit humanity, generate new employment opportunities, and increase productivity. This will lead to the upgrading and reskilling of workers [16]. Somroo [17] also states that modern automated industries are considering adding the human element back into their technological systems and strategies to get the most value from automation. It combines the best of both worlds, the speed and precision of automation with the cognitive abilities and critical thinking of humans [9]. Machines and humans should work as collaborators and not as competitors [9].

3.1.2 Sustainability

Organisations concentrating only on profit are finding it increasingly difficult to succeed in a global, unpredictable, and competitive environment. For companies to be sustainable, they need to achieve a symbiosis between economic, technological, social, and ecological aspects [9], [11]. Ahamed [11] states that Industry 5.0 emphasises sustainable supply chain management, incorporating elements such as 'employee education and training, working conditions, the balance between productivity and wages, technology versus human redundancy, optimal product quality, sustainable governance, and a business ethics code'. Sustainability is also argued to be driven by the implementation of digital transformation and pro-social and pro-environmental solutions in organisations [18]. There is a shift in typical economic models to circular economy models to improve overall sustainability considering social and environmental needs and challenges [18].

There is also a rise in environmental policies to reduce waste material and improve waste management. More companies are prioritising environmental sustainability, aligning with the growing demands of international organisations, government regulations, and customer expectations [8]. The 6R principles of upcycling are introduced to accompany Industry 5.0 namely, recognising, reconsidering, realising, reducing, reusing and recycling [17],[18], [19]. Akundi [20] also mentions the 6R principles as a means to promote human values and needs.

3.1.3 Resilience

Resilience is the organisation's ability to return to a stable state after expected and unexpected conditions such as geopolitical shifts and global crises, ensuring that critical infrastructure remains operational during challenges [21] [22]. It involves building robust supply chains, systems, networks, and societies capable of responding quickly to threats and recovering efficiently from failures [14]. Industry 5.0 improves resilience in manufacturing by using flexible, agile, and adaptable technologies [18].

There are two types of resilience, "self-resilience" for employees and "system resilience" for human-machine systems, this encourages collaboration to reach goals that neither could reach independently [21]. This allows for a robust system that can adapt to changes [23]. The European Commission found that enforcing environmental and social governance criteria leads to better resilience [24]. Resilience in organisations is especially important where they provide critical services such as healthcare or security [24].

3.1.4 Personalisation and Customisation

A key concept in Industry 5.0 is moving from mass production to mass personalisation and customisation [8]. This can be achieved through the collaboration between humans and advanced, intelligent, high speed and precise machines [17]. By including critical thinking within processes, mass personalisation can be achieved based on customer needs and expectations.

The demand for human touch is expected to grow as customers increasingly seek to express their individuality through their purchases. This trend reflects a new level of personalisation and a sense of luxury that businesses must address [11]. Kovari [13] states that the combination of human skills and smart factories will enable companies to respond quickly to market changes and demands.

3.1.5 Bioeconomy

The bioeconomy is described as one of the visions for Industry 5.0 by focussing on breakthroughs in agriculture, healthcare, and biosciences [25]. Sindhwani [25] defines a bioeconomy as 'the conversion and production of renewable biological sources into value-added products such as food, bioenergy and biobased products'. This includes a wide variety of industries such as agriculture, forestry, fisheries, technology, energy, and manufacturing industries.

Bioeconomy will act as an enabler for the symbioses between ecology, industry, and economy through the use of bioinspired technologies [14], [21]. The demand for bioinspired technologies is expected to increase due to the growing need for clean, affordable, and sustainable energy. These technologies will be part of bioinspired systems [26].

3.2 RQ2: What are the key components of the Industry 5.0 frameworks?

A recent report by the European Commission outlines six desired characteristics of technologies that support the concept of Industry 5.0 [27]:

- Human-Centric Solutions
- Bio-Inspired Technologies
- Real-Time Digital Twins
- Cyber-Safe Data Transmission
- Artificial intelligence
- Technologies for Energy Efficiency and Trustworthy Autonomy

Figure 2 shows the components most common to least discussed in the 30 articles included. Each of these components will be discussed individually to understand the definition and application.

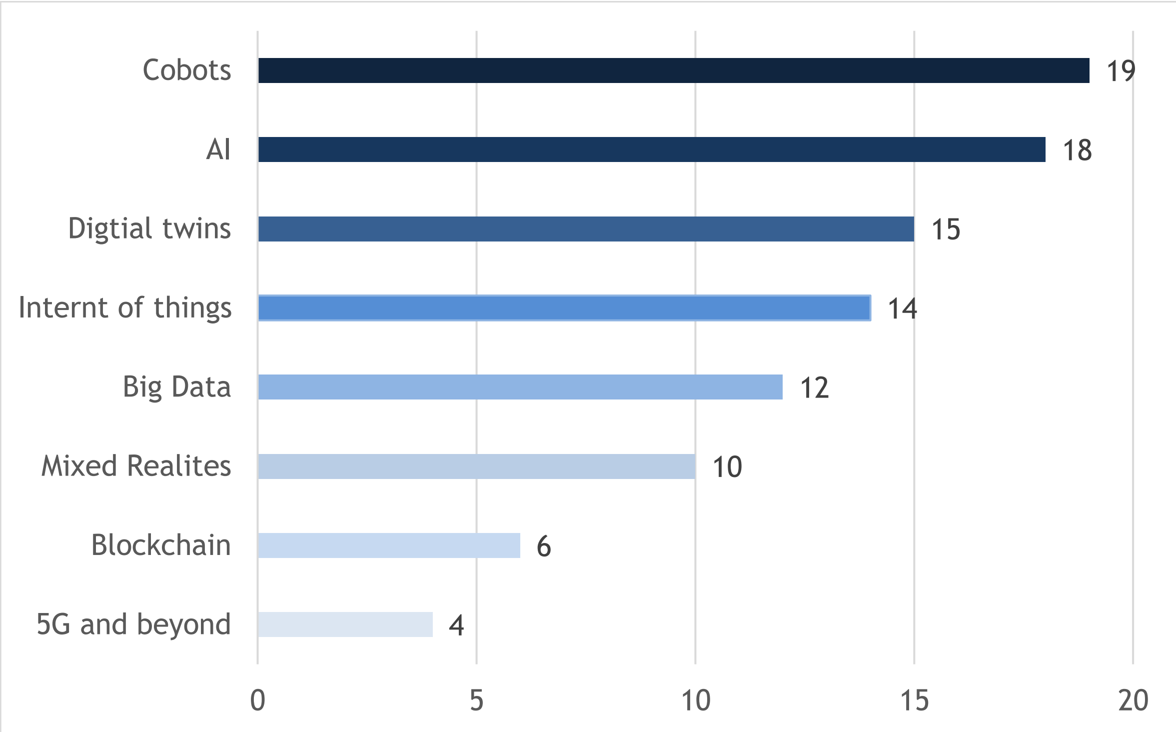


Figure 2: Number of articles discussing industry 5.0 Components

3.2.1 Collaborative Robots (Cobots):

According to George [8], the definition of a cobot is a robot designed to physically interact with people in a shared workplace where safety is prioritised. These robots collaborate with humans on the production line and learn from them. Cobots can recognise and adapt to the activities of their colleagues, creating a safer and more efficient work environment [13].

Specifically in a manufacturing setup, there are two concepts: a) Allowing humans to work on customised, personalised and creative tasks. b) Utilising robots for repetitive and labourintensive tasks. This can help mitigate risks on the job [20]. By integrating human intelligence and cognitive processes into computers through cognitive computing, they can create more value add. Cobots are also discussed when describing smart factories and improved communication between components and humans [17]. Humans are connected to smart factories through intelligent devices [9].

Another author discussed cobots' role in intelligent healthcare, where cobots can monitor patients' conditions and assist doctors in performing surgeries and handling routine medical tasks allowing doctors to focus on more complex tasks [13]. In manufacturing, consider an example where a technician is performing maintenance on a piece of machinery. The cobot, equipped with a camera, observes the technician's actions, analyses the images using machine learning, and predicts the technician's next steps using fNIRS (functional Near-Infrared Spectroscopy) and deep learning. The cobot then provides the necessary tools and parts to assist the technician when needed [21].

3.2.2 Artificial Intelligence (AI):

AI is a collection of technologies based on AI models and techniques, including machine learning and natural language generation. It is designed to provide services or insights that are challenging or impossible to attain solely through human effort or conventional technologies [28].

By leveraging AI technology together with human-centred digitalisation, we can increase the productivity and sustainability of an organisation. It is the responsibility of organisations to realise the benefits of AI by adopting, extending, and implementing AI tools [29]. For example, artificial intelligence is used to improve predictive forecasts and, therefore, reduce excess manufacturing [18]. According to Akundi [20], AI can meet the personalisation needs of customers in the manufacturing industry and provide faster feedback [30].

3.2.3 Digital Twins

Digital twins are virtual replicas of physical devices or systems that collect real-time data and are used to gather insights and analytics [28]. These twins assist organisations in developing and optimising production processes and can improve predictive maintenance in the manufacturing industry [13]. In the banking sector, Digital Twins can customise products and services, improve the accuracy of automated financial statements, quickly identify technical issues, improve risk management, and avoid investments in high-risk projects [17].

3.2.4 Internet of Things (IoT)

It refers to the network of interconnected software, sensors, and devices that communicate data with other devices, systems, applications, and users to create a comprehensive network infrastructure [28]. It connects different people, systems, data, devices and processes [30]. With the use of smart sensors, IoT devices, and human insights, organisations can gather and analyse data to gain insight into processes [13] [14]. IoT data gathering and analysis are useful when monitoring products and machinery to achieve predictive maintenance [30]. In the banking sector, IoT is used to address challenges related to customer retention and satisfaction [17].

3.2.5 Mixed Realities (Augmented Reality (AR) and Virtual Reality (VR))

Augmented reality integrates digital information with the physical world through computer-generated content such as text, video, or animated 3D models [28]. Virtual reality provides a fully virtual experience that completely isolates the user from the real world, utilising advanced user-computer interfaces for simulation and real-time interaction [28].

This type of technology allows workers to interact and engage with processes and equipment in virtual environments [13]. Since the operator is in a safe environment, this makes it a great tool for training and education and is cost-effective and time-saving [31] [32].

3.2.6 Big Data Analytics

Big data is large volumes and a variety of data sets that need to be handled and processed accordingly [14] [28]. Using big data can support decision-making strategies and automation [30]. Big data analytics helps to understand customer behaviour, product promotions, and process customisation thus improving production efficiency, and reducing costs [17]. It enables organisations to develop successful business strategies and maintain their competitive edge. The use of human creativity and data insights is vital for optimising the value derived from big data [10].

3.2.7 Blockchain

Blockchain creates transparency and provides secure storage for encrypted data [30]. Blockchain technology is used to improve energy efficiency and resource use through process management [18]. It is used to create secure and transparent transactions when improving ESG reporting [14]. Blockchain also has significant potential to improve supply chains by increasing transaction efficiency, reducing costs, and improving security [10].

3.2.8 Other Technologies

Other technologies mentioned or briefly discussed in the articles include exoskeletons, drones, additive technology, edge computing, cloud computing, cyber security, multilingual speech and gesture recognition, tracking technologies, bioinspired safety and support equipment, decision support systems, smart grids, machine learning, federated learning, internet of intelligence, quantum computing, cognitive robotics, bioinspired technology, smart cities, holography, bionics, hybrid intelligence, radio frequency identification (RFID), cognitive cyber-physical systems, human interaction and recognition technologies, intelligent energy management system (IEMS), industrial smart wearable (ISW), horizontal and vertical system integration, and 5G and beyond.

4 DISCUSSION

While Industry 4.0 is focused on technology, Industry 5.0 is focused on value. Industry 4.0 provides the tools and technologies, and Industry 5.0 uses them to create a positive impact on societal and environmental levels. This scoping review has identified key concepts and components essential for the successful implementation of Industry 5.0 frameworks, offering valuable insights into the future of industrial practices. Based on the results above an Industry 5.0 framework is created and visualised in Figure 3.

Figure 3: Industry 5.0 Framework: Key Concepts & Components

Industry 5.0 places human well-being at its core, emphasising the collaboration between humans and machines using the 5C principles (Coexistence, Cooperation, Collaboration, Compassion, Coevolution). Integrating human skills such as creativity, decision-making, and problem-solving with advanced technologies like collaborative robots (cobots) enhances workplace safety, reduces errors, and leads to the reskilling and upskilling of the workforce. Humans still need to make certain immediate or unscheduled decisions that robots will not be able to.

Sustainability in Industry 5.0 encompasses economic, technological, ecological and social dimensions. It involves sustainable supply chain management practices, circular economy models, and the application of the 6R principles (recognising, reconsidering, realising, reducing, reusing, and recycling). Organisations need to work within the limits of our planet. Companies must balance profit with social and environmental responsibilities to succeed in a global, unpredictable environment. Resilience is critical for organisations to withstand and recover from disruptions. Industry 5.0 enhances resilience through flexible, agile, and adaptable technologies. Building robust supply chains and systems capable of quick response and recovery is essential. Enforcing Environmental and Social Governance (ESG) criteria further strengthens organisational resilience.

Resilience is the ability of an organisation to maintain stability during crises, ensuring critical infrastructure remains operational. It involves building robust supply chains, systems, and networks that respond quickly and recover efficiently. Industry 5.0 enhances resilience through flexible, agile, and adaptable technologies. The two types of resilience are "self-resilience" for employees and "system resilience" for human-machine systems, promoting collaboration for achieving shared goals.

From a customer perspective moving from mass production to mass personalisation and customisation is key in Industry 5.0. Advanced technologies like AI and digital twins enable companies to tailor products and services to individual customer needs, enhancing satisfaction and loyalty. From a system perspective, the bioeconomy focuses on the sustainable production and conversion of renewable biological resources. Bioinspired technologies, driven by the need for clean, affordable, and sustainable energy, promote the symbiosis between ecology, industry, and the economy.

Lastly, Industry 5.0 will positively impact employees by exploring different and alternative job roles and training through reskilling and upskilling. It will enhance the quality and health of their working environment through innovative solutions and better organisational governance and ethics. The review identified several critical components supporting the Industry 5.0 framework, including collaborative robots, artificial intelligence, digital twins, the Internet of Things, mixed realities (AR and VR), big data analytics, blockchain, and other emerging technologies. These components collectively enhance human-machine interaction, improve operational efficiency, and drive innovation.

The transition to Industry 5.0 presents several challenges, including legal, psychological, regulatory, and social issues. The evolving roles of HR and IT departments will need to address these challenges by fostering a culture that supports human-machine collaboration and continuous learning. Additionally, integration and technological challenges, such as ensuring interoperability between systems and maintaining data security, require robust leadership and strategic planning.

5 CONCLUSION

Industry 5.0 represents a transformative phase in industrialisation, focusing on human-centric, sustainable, and resilient practices. By integrating advanced technologies with human skills, organisations can achieve greater productivity, customisation, and sustainability. The concepts and components identified in this review provide a foundational framework for the successful implementation of Industry 5.0, guiding organisations towards a future where technological advancements and human well-being are harmoniously balanced.

This study is limited by the scope of the available literature and the rapidly evolving nature of Industry 5.0 technologies and frameworks. Future studies should focus on developing comprehensive implementation strategies for Industry 5.0, considering the unique needs of various industries. This paper lays a robust foundation for future empirical investigations across various industries. Industrial engineers can utilise this framework to assess the transition and implementation of Industry 5.0 within different sectors. Research should also investigate the long-term impacts of Industry 5.0 on workforce dynamics, environmental sustainability, and economic growth. Recommendations to organisations include investing in employee training and development, fostering innovation through collaboration, and adopting flexible, adaptive technologies to improve resilience. Additionally, policymakers should create supportive regulatory environments that encourage sustainable practices and technological integration.

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