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Review

The Role of Ergonomic and Human Factors in Sustainable Manufacturing: A Review

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Abstract: The study and implementation of ergonomics are vital for the growth of industries and improvement in work cultures. Sustainable manufacturing cannot be achieved without the implementation of human-factor ergonomics. Ergonomics is used to analyze the link between research studies and industrial practices in order to maximize the efficiency of processes by keeping in view the well-being of workforce. Designing tools, tasks, machines, systems, jobs, and settings for efficient, safe, and successful human usage involves applying knowledge about human behavior, abilities, and limitations. Workers are the backbone of the manufacturing economy. The review outlines significant advancements in preventing ergonomic problems during the design stage of the manufacturing process to achieve sustainability. The bibliometric analysis is used to identify the literature base for ergonomics. To maximize the benefits of ergonomics and to integrate sustainable practices, various methods are required to organize existing processes and technologies. The human-centered design identifies problems and aligns the output with the intended objectives of sustainability. The goal of human factors and ergonomics is to successfully integrate people into systems and develop the manufacturing processes around the well-being of workers and sustainability principles. Similarly, ergoecology, eco-ergonomics, and green ergonomics are frequently used for sustainable manufacturing. Achieving sustainability in manufacturing is not possible without considering human ergonomics. Ergonomists frequently research management, planning, and other topics to increase the efficiency of the manufacturing process. Efficient worker performance and quality of life can be enhanced through work design, management, and organizational ergonomics. Human ergonomics relates sustainability with cognitive variables such as situational awareness, human reliability, and decision-making abilities. This review explains the role of human factors and ergonomics for sustainable manufacturing.

Keywords: ergonomics; Industry 4.0; human factors; sustainability; manufacturing

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1. Introduction

Ergonomics represents both a scientific field and a field of professional practice. Individuals who specialize in this field typically identify as either researchers or practitioners, and these two roles are frequently referred to as research and practice in general. Some ergonomists work in both research and application. There has been some evident conflict between research and practice within the field. While this tension is not exclusive to the subject of ergonomics, ergonomics is ideally positioned to examine the interface between researchers and practitioners to maximize engagement between these two groups of stakeholders. Not enough attention may have been invested in comprehending both the strengths and limitations of ergonomists, given their various backgrounds in terms of experience and education. Another suggestion to ease the conflict between research and practice is to better understand the specific requirements of the end users of ergonomics research. Research of this nature will be better equipped to produce tools and assessments that assist ergonomists in meeting the organizational goals and expectations of their customers [1]. There exists a third field related to academics that primarily focuses on education, training, and other academic activities related to ergonomics. It involves teaching the principles of ergonomics to, imparting knowledge to, and developing skills in individuals intending to pursue careers in ergonomics.

Designing tools, tasks, machines, systems, jobs, and settings for efficient, safe, and successful human usage involves applying knowledge about human behavior, abilities, and limitations. This not only optimizes worker safety, health, and comfort but also ensures the enhancement of efficiency and productivity. Ergonomics, known as "the laws of the job", is derived from the Greek terms, "ergon", which means "work", and "nomos", which means "laws". The Polish natural scientist Jastrzebowski coined the phrase in 1857 [2]. Later, Murrell independently created and publicly formalized the word ergonomics in a 1949 publication [3]. In the early 1960s, ergonomics activities and research mostly started in Industrial Developing Countries (IDCs) [4].

Humans still play a vital role in the sociotechnical change that is leading to the factory of the future [5]. Numerous arguments have been put forward in the literature [6] for the value of ergonomic principles in work and workplace design, as well as the advantages of using human-centered design concepts. To improve assembly system design while considering ergonomic factors, Battini et al. [7] suggested a concurrent engineering approach. Djapan et al. [8] proposed a novel approach for assessing risks associated with human and technological factors. He also developed a novel technique for risk assessment concerning human, organizational, and technical/technological variables. The analysis of anthropocentric viewpoints within Industry 4.0 emphasizes how the digital transformation of manufacturing production systems is redefining the function of the human operator and provides new chances to support workers from both cognitive and physical perspectives [9]. To speed up the process of designing an assembly line in this regard, Caputo et al. [10] created a system that made use of digital twins of workstations. Using the information on operator position and workload, Alkan et al.'s software solution [11] for designing virtual manufacturing processes is based on digital human models.

The studies outlined above represent a significant advance in preventing ergonomic problems during the design stage of a production process. However, to create ergonomic workstations, a technique that compiles and organizes existing techniques and technologies is required. The qualitative and quantitative definition of the problem is rarely supported by existing methods, and there is a lack of an unbiased ergonomics analysis to validate the solution. With the help of the Internet of Things (IoT), this study intends to promote the human-centered design of manufacturing processes, from problem identification to the objective evaluation of benefits. Research and development of the interaction between the operator and the work equipment, also known as interaction design, is a crucial component in sustainable manufacturing [12]. For sustainable developments, the manufacturing processes and business practices need to be sustainable in providing safe environment and great working conditions. There are many challenges during the incorporation of sustainability, and they are ecological and social effectiveness, economics, and management issues [13]. Businesses and manufacturing industries must incorporate all these varied aspects of sustainability, concentrating not just on social or environmental performance but also on commercial and economic sustainability [14]. Concepts like proactive occupational health and safety, human-centered design of work, individual-based and group learning, employee involvement, workspace well-being, and balance in work-life are examples of how sustainability is accomplished with the successful integration of ergonomics in any industry [15]. In the context of sustainability, the promotion of workplace well-being presents both a problem and a possibility for companies to achieve objectives like "the ability of coming generations to satisfy their requirements" by integrating ergonomics. Companies are being forced to become more flexible as a result of the frequent changes in the market, high degrees of customization, and desire for products with shorter life cycles [16]. A workstation's design specifications should take the standardization of activities and products into account since it is a crucial component of manufacturing flexibility [17]. The equipment design is made more difficult by the need to identify solutions that simultaneously boost performance and enhance operator well-being [18].

This review outlines the importance of ergonomics and human factors in sustainable manufacturing. This review starts with an explanation of human factors and the role these factors play in ergonomics. Ergonomics is further categorized to explain different aspects of the organizational structures including human factors. It is further explained how optimizing human factors enhances productivity. Ergonomics and its relationship with workplace well-being, sustainability, and cross-cultural differences are discussed, leading to the components of sustainability and the challenges in implementing them in a workplace. The review incorporates bibliometric and PRISMA analysis to further cement the importance and role of ergonomics in Industry 4.0 based on the keywords. After this, the scope and definition of human factors are explained, and the relationship of human factors with business management, organizational strategy, sustainable developments, and human–system interactions is discussed. The shift in global work culture, demographic shifts, and social interactions are explained. Furthermore, the importance of sustainability in Industry 4.0 and its role in additive manufacturing in combination with information technology are discussed. In the end, how ergonomics can efficiently design jobs with human workability, employability, and the integration of research hand innovation, with the changing landscape of the manufacturing industry, is discussed.

1.1. Human Factors and Ergonomics

The sociotechnical system theory states that an efficient coupling of system surroundings and personnel increases the effectiveness of the latter [19]. Based on this hypothesis, the study concentrated on adversely affecting human aspects to provide a greater synergy with the lean system. Human factors and ergonomics (HFE) in collaboration with sustainability principles can produce an efficient combination. Optimizing the interactions between workers and system settings to ensure worker performance and well-being is the focus of the scientific field of human factors, ergonomics, and sustainability [2]. Physical ergonomics, organizational ergonomics, and cognitive ergonomics are the three basic categories under which HFE can be classified [20]. The first area of physical ergonomics involves human anthropometric, anatomical, and biomechanical traits and physiological aspects of physical exercise [21]. Organizational ergonomics is the study of methods of optimizing sociotechnical systems, such as organizational structure, policies, and procedures [22]. Thirdly, cognitive ergonomics focuses on how human interaction with other system components can be improved by optimizing mental processes (such as motor reaction, reasoning, memory, and perception) [23]. HFE serves as a catalyst to improve workers' productivity within an organization [24].

HFE is concerned with the mechanisms that enable human interaction with the environment. The environment is complicated and includes the social (other people/cultures), organizational (methods by which activities are managed), and physical environments (things). The system may be a work system, in which the environment is the workplace, and the human beings are the workers, or it may be a system of goods or services (where the human is a product or service user, and the environment is the context in which products or services are used or received). The goal of HFE is to better integrate people into systems and develop integrative wholes to mutually improve performance and well-being. This is achieved by adapting the environment to the individual. HFE often adopts a hierarchical approach, where designing the environment to suit the human is prioritized, and selecting or training individuals to fit the environment or system is only taken into consideration when the former is impractical [25]. Humans function better in environments that are more conducive to their needs. A significant amount of knowledge and expertise on interactions between people and their environment, as well as techniques for system analysis and design, has been generated and recorded by the HFE community over the past 50 years [24]. The three fundamental tenants of HFE are the following: (1) it is design driven, (2) it adopts a system approach, and (3) it is concerned with two related outcomes, i.e., performance and well-being [26].

1.2. Workplace Well-Being and Safety

The definition of workplace and well-being of workers includes making sure that employees are secure, engaged, and happy with work. Learning about ergonomics along with sustainability may lead to potential answers or ideas for promoting well-being at work. Human factors and ergonomics and sustainability promote productivity, efficiency, and effectiveness while contributing to social sustainability and respective growth. Ergonomists can contribute by comprehending employment practices, enhancing and promoting designs of environmentally friendly products, and creating efficient and effective work systems that ensure the safety of operations of these intricate systems [27]. The complexity of these systems extends beyond technological aspects as the interconnected systems enable various other issues including ecological and financial dimensions. These complexities give rise to far-reaching intricacies for global economies, industries, and businesses. The organizational structure of manufacturing and distribution networks are expanded around the globe, incorporating culturally diversified workforce. The goods and services produced by this workforce are now used by a wide range of consumers around the globe. This has resulted in a dynamic shift where labor and product/consumer systems are now characterized by a wide group of people from various cultural backgrounds with unique traits and objectives. Consequently, environments that were once carefully planned and crafted for specific groups may prove inadequate for another. HFE can combat this trend of increasing cultural diversity by helping to design products and services that are cross-culturally compatible with a broad consumer base, as well as production and distribution systems that are cross-culturally compatible with a diversified workforce [28]. Cross-cultural design takes into consideration the fact that individuals from other cultures have varying capacities and ambitions, which have an impact on the way in which the systems they are a part of are designed. Examples of this include global distribution systems and the creation of international media [29].

Professionals in the fields of safety, health, and the environment are becoming increasingly interested in sustainability. Legislative rules act as a catalyst for shifting businesses and manufacturing from unsustainable practices to more environmentally friendly ones, but it is important not to overstate their impact. Sustainable manufacturing aids in resolving certain issues brought on by rising energy, waste management, and raw material costs. Sustainable growth aims to strike a balance between social, ecological, and economic challenges [30]. This is often a very basic level issue. Sustainability and ergonomics essentially just boil down to the same thing: resource conservation. These resources are often considered to have environmental impact in the context of sustainability. Despite this point of agreement, debates on sustainability are just starting to include human factors, safety, and ergonomics. Human factors and ergonomics and sustainable manufacturing are a part of future sustainable developments and manufacturing. This involves taking into account pertinent human factor concerns while manufacturing operations and procedures are developed from the perspective of the various phases of the product life cycle [31].

1.3. Components of Sustainability

Conventional ergonomics has been extensively changed by including the components of sustainability—ecological, economic, and social objectives. HFE should not only recognize but also strive for "concurrent fulfilment of all three major components of sustainability". Some definitions include sustainability in ergonomics, but this is an ongoing debate. Despite all these theoretical discussions, there is a significant gap between the principles of sustainable developments and HFE practices [2]. The gap is due to the limited attention given to the social, ecological, and economic aspects of sustainability within ergonomic studies. Most of the work focused on the economic aspects and economics received far more attention than the other dimensions such as social and ecological, which are nascent but largely theoretical. A paradigm shift is necessary to bridge this gap in sustainability for both the theoretical knowledge and applications of HFE [32]. Understanding and implementing participatory ergonomics and other constructivist approaches can revolutionize the interpretations and interventions for human–technology interactions. This transformative approach pushes HFE to go beyond its traditional focus on human rights and safety concerns and actively incorporate deep considerations for environmental sustainability [14].

2. Establishing the Literature Base via Bibliometric Analysis

Through a bibliometric analysis of the relevant literature, this review aims to examine the role of ergonomics and human factors in sustainable manufacturing. Using a thorough search query, the data supporting this review were carefully collected from the Scopus database. Numerous publications were found after the initial search, and they were further evaluated for relevance to the research topic based on their titles and abstracts. The following inclusion criteria were established for the articles:

- The article ought to be published in a journal with peer review.
- The interaction between sustainable manufacturing, ergonomics, and human factors should be highlighted in the article.
- To clearly explain the significance of ergonomic and human factors in sustainable manufacturing, the paper must provide empirical data or findings.

The articles included in this review were carefully chosen for their direct relevance to the nexus of sustainable manufacturing, ergonomics, and human factors. These papers provide interesting insights into how ergonomics and human factors relate to topics like sustainability, eco-design, green manufacturing, and the use of cutting-edge technologies like Industry 4.0, Digital Twins, and IoT in production processes.

Articles that, despite being pertinent to ergonomics, human factors, or sustainable manufacturing, veered off in other directions or did not specifically address the integration of ergonomics and human factors in sustainable manufacturing were not included. Data extraction involved a detailed analysis of the selected papers. This information was then organized and combined to find recurrent themes, patterns, and consistencies within the different articles. Additionally, each article's important conclusions and deductions were briefly summarized, offering a thorough overview of the body of knowledge. Figure 1 shows the PRISMA flow diagram which depicts how the data were identified, screened, and included.

2.1. PRISMA Analysis

The bibliometric data displayed spans a ten-year period, from 2011 to 2023, and is suggestive of an active and steadily developing field of research focusing on ergonomic and human factors in sustainable manufacturing. An impressive 30.32% yearly growth rate indicates a booming interest in this field, indicating its growing significance and applicability in both academic and industrial areas. The 95 different sources, which include journals and books, demonstrate the depth of the subject's investigation and the breadth of the conversation surrounding it. This suggests a thorough and multifaceted approach of comprehending how ergonomics and human aspects are incorporated into sustainable manufacturing. The data highlights the recentness and scholarly significance of the studies in this field, which have 150 documents with an average age of 2.39 years and an average citation rate of 7.94 per document. The abundance of Keywords Plus and Author's Keywords indicates that there are several sub-topics and research focuses within the main issue, emphasizing the diversity of thematic focus and the breadth of field investigation. A well-established and intricately integrated body of knowledge is further demonstrated by the substantial reference base, which includes 5317 references. This suggests a strong scholarly background and a strong intellectual foundation. The engagement of 419 authors, with some of them contributing to single-authored studies, demonstrates the diversity in authorship and the integration of solitary and group research endeavors. The average of

3.19 co-authors per document and a sizeable portion of international co-authorships, which show a global and collaborative research environment, further emphasizing this mix. Such worldwide cooperation demonstrates a range of viewpoints and methodologies, which promotes a more thorough and nuanced understanding of the issue. The breakdown of document kinds demonstrates a diverse body of scholarly work. A balanced academic conversation, combining in-depth exploration with immediate discourse and discussion on developing ideas and practices, is demonstrated by the presence of articles, book chapters, conference papers, conference reviews, editorials, and reviews. This diversity shows a balanced approach to theory and practice, demonstrating that the field is making progress not only intellectually but also through tackling practical problems and applications. The significant annual growth rate and the variety of sources and document kinds highlight how the area of ergonomics and human factors in sustainable manufacturing is developing and expanding. The research's collaborative character, global perspective, and interdisciplinary approach broaden and deepen our understanding of this topic. Recent contributions to the topic have had a substantial intellectual impact, signaling further growth and acknowledgment. This dynamic, influential, and varied field of study is distinguished by a noteworthy synthesis of theoretical innovations and real-world applications, underscoring its significance and relevance in the modern academic and industrial scene.

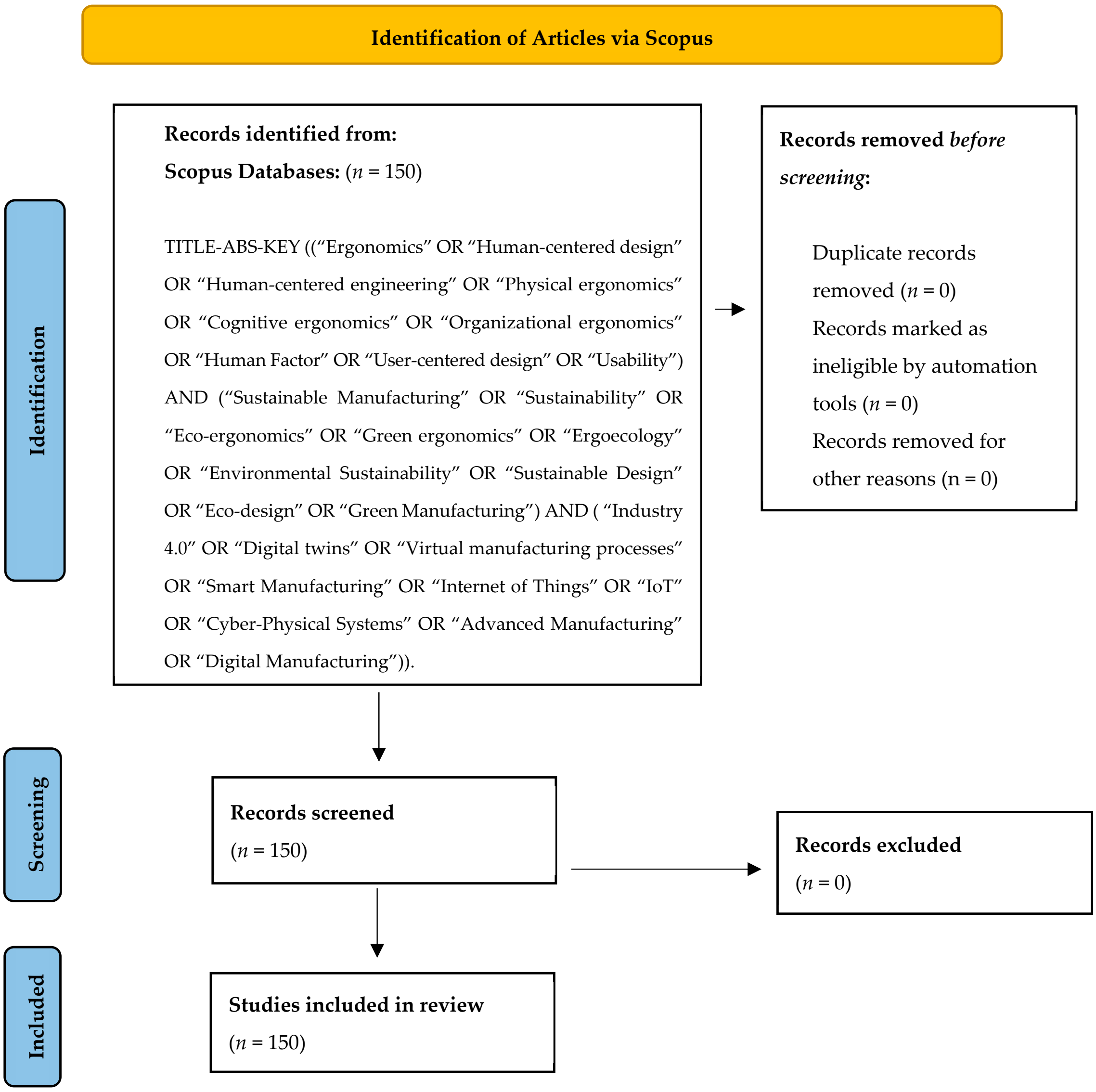

Figure 1. Search strategy using PRISMA flow diagram.

2.2. Prominent Keywords

The information on the most pertinent author keywords provides a detailed understanding of the wide range of issues and ideas that the study of ergonomic and human factors in sustainable manufacturing is built upon. The most popularly used keywords, including "industry 4.0", "sustainability", "internet of things", "human factors", and "ergonomics", highlight how advanced technologies, human-centered design principles, and sustainability considerations are converged in this field. Keywords like "IoT", "industry 5.0", "artificial intelligence", "digital twin", and "human-centered design" are prominently present, reflecting the industry's continual evolution and its focus on integrating cutting-edge technologies to improve human-centric production methods. The focus on "sustainable development", "circular economy", "social sustainability", and "sustainable manufacturing" reveals a rising understanding of the necessity for ecologically responsible practices and the pursuit of social equality in the manufacturing sector. Additionally, the use of terminology like "human-robot collaboration", "usability", "blockchain", "machine learning", and "big data" denotes the investigation of cutting-edge approaches and solutions to handle problems and improve procedures in sustainable manufacturing. The variety of technology-related phrases, like "cyber-physical systems", "smart manufacturing", and "augmented reality", demonstrates how digital innovations are being incorporated to promote productivity and sustainability in manufacturing operations. Interestingly, the list also includes more specialized and nuanced phrases, such as "operator 4.0", "design thinking", "green manufacturing", and "supply chain", which indicate the investigation of specialized themes and the development of new concepts and frameworks within the sector. The use of words like "ethics", "trust", "resilience", and "accessibility" indicates that ethical and social considerations were considered when developing and implementing sustainable manufacturing practices. Additionally, the lengthy list of distinct keywords highlights the diversity of issues being researched and the breadth of research areas, ranging from "3D printing" and "5G" to "energy management", "smart cities", "climate change", and "design for sustainability". This broad keyword spectrum exemplifies the field's complexity and the range of approaches being taken to comprehend and improve the role of ergonomics and human factors in sustainable manufacturing.

2.3. Word Clustering

Figure 2 shows the outcomes of a clustering study carried out on a collection of documents. The texts are grouped depending on how well references are coupled (field "CR"), with the "walktrap" clustering technique being used. The parameters of the analysis are also provided, including the number of documents (n = 250), the lowest frequency (minfreq = 0), and others. A Cluster Number, a Normalized Local Citation Score, and a unique identity (such as "WANG X, 2023, IEEE TRANS SYST MAN CYBERN SYST") are alloted to each publication. While the Cluster Number designates the exact cluster to which the document belongs, the Normalized Local Citation Score reveals the citation impact of the document in its local cluster. The clusters are identified by their frequency, centrality, influence, and distinctive color coding. They are labelled with a combination of phrases (label.term = "DE"). The terms used to designate the clusters are probably drawn from the keywords or topics of the papers, and they provide an idea of the primary themes of the texts contained inside each cluster. For instance, Cluster 1 is marked as "industry 4.0—conf 42.1%, human factors—conf 45.5%, social sustainability—conf 75%", indicating that these are the themes that are the most common in this cluster. The percentages may correspond to the proportion of documents in the cluster that contain these terms. The information shows that there are 18 clusters made up of the documents, each with a different theme like Industry 4.0, Human Factors, Sustainability, Deep Learning, Artificial Intelligence, Internet of Things, etc. The number of articles in each cluster is indicated by the frequency column in the label data, while the cluster's centrality and impact columns indicate the cluster's relative relevance in the network. Figure 3 shows the co-occurrence network for ergonomics and related keywords, while Figure 4 shows the thematic map for network visualization.

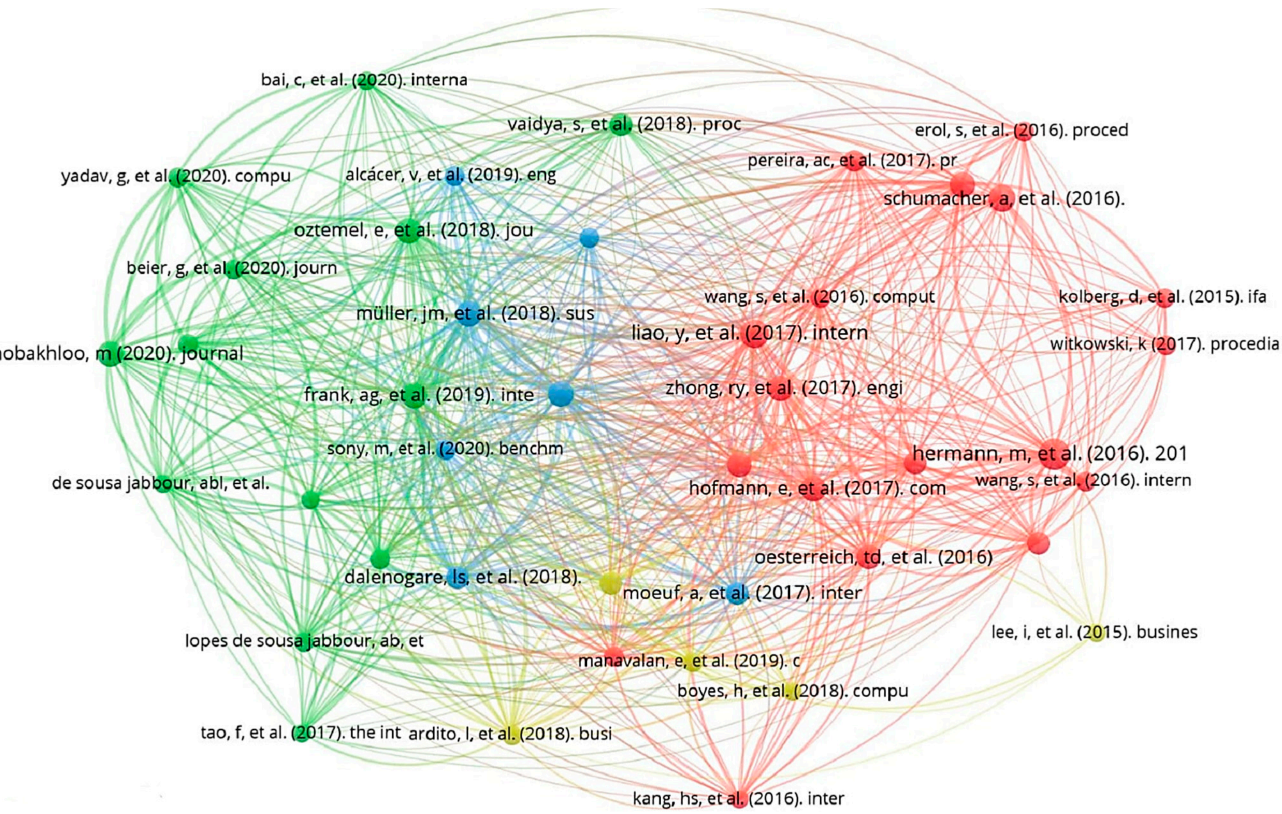

Figure 2. Word clustering by coupling.

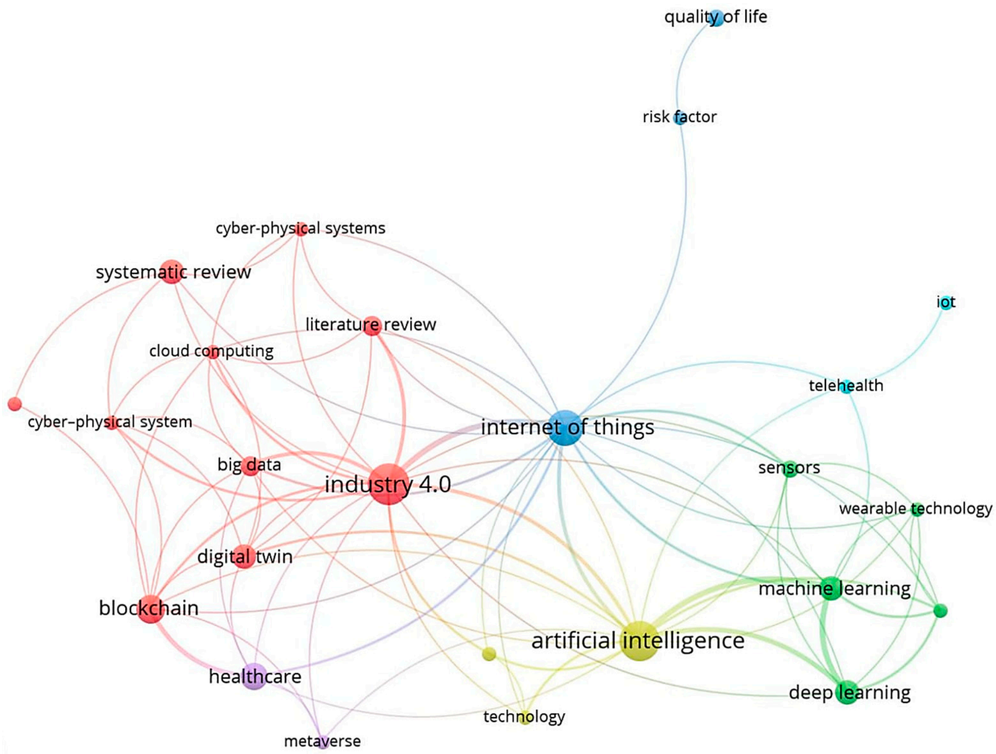

Figure 3. Co-occurrence network for ergonomics and related keywords.

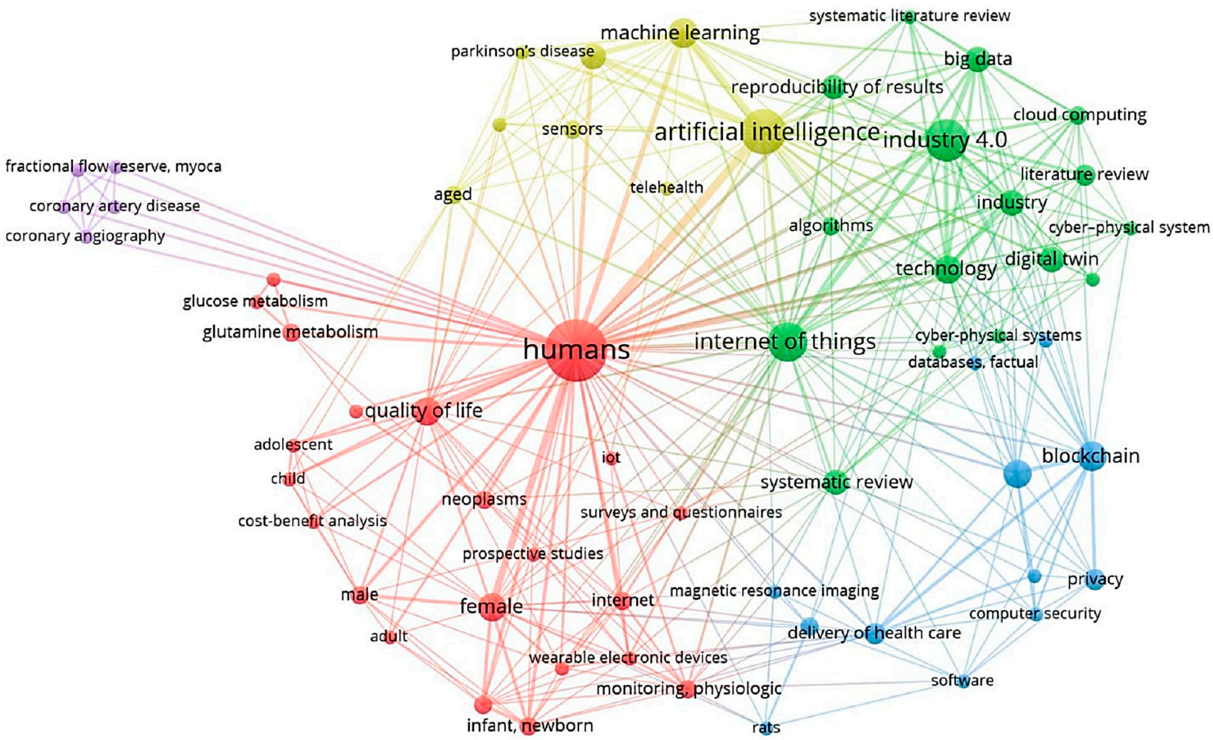

Figure 4. Thematic map for network visualization.

3. Human Factors

The term "human factors" does not necessarily refer to people as the name might imply. It is primarily concerned with being aware of human limitations and creating a workplace and tools that take human variability into account and make human performance more effective, secure, comfortable, and enjoyable [33]. Long-term business management and strategy implementation recognizes the need to match abilities to the tasks being performed [34]. Understanding how individuals interact with other components of complex systems is at the heart of the human factors study. To support, maintain, monitor, redesign, and use all of these complex systems effectively, one must have a thorough understanding of ergonomics [35]. To improve human wellness, system performance, and dependability, human factors apply scientific knowledge and concepts along with lessons learned from prior occurrences and operating experiences [36]. The field helps with the design and assessment of systems, settings, products, and organizations, as well as tasks, roles, and tools. It emphasizes the establishment of sustainable and safe workplace cultures as well as the innate traits, requirements, capacities, and limitations of individuals. In addition to having a direct impact on job satisfaction, human factors can concurrently impact the safety culture of a company [35,37]. As emphasized by McCormick [38], "The central focus of human factors relates to the consideration of human beings carrying out functions as:

- the design and creation of man-made objects, products, equipment, facilities, and environments that people use.
- the development of procedures for performing work and other human activities.
- the provision of services to people; and
- the evaluation of the things people uses in terms of their suitability for people".

The terms "human factors" and "ergonomics" have been used interchangeably while ergonomics is a broader field that includes physical, cognitive, and organizational aspects of work and life, and human factors are considered a subset of ergonomics, focusing on the psychological and physiological aspects of human performance and behavior in relation to design [37]. However, HFE refers to a distinct and interrelated field of study that concentrates on the human–artifact nature and interaction by taking into account the design, science, technology, engineering, and management of human-compatible systems, which include a range of artificial and natural commodities involving processes and living environments [39]. HFE is concerned with the mechanisms that enable human interaction with environmental factors. The environmental factors are multifaceted and comprise the social environment (other individuals, society), the environment of the organization (the control and management of various activities), and the physical environment (objects) [40]. Nowadays, ergonomics is a well-established subject that includes experts from several fields collaborating to build sociotechnical systems to adapt them to human requirements and well-being. It is understood from the perspective of manufacturing businesses that any sophisticated technology system involving humans is incredibly reliant on the social and organizational context in which it functions. The goal is to make sure systems are designed and planned in a manner that maximizes the role of humans in production to minimize the possibility of design-related risks to well-being, process or personal safety, or the overall environment.

The contribution and prospects of HFE to face the problems related to sustainable development have been the subject of continuous discussions for several years [41–44]. According to Stanton and Stammers [45], there is a logical connection of ergonomics with sustainable development. The World's Commission on Environment and Development (WCED) definition and the "triple bottom line" strategy were particularly referenced by Zink et al. [46]. Zink et al. [46] urged ergonomists to contribute by comprehending employment-related practices, enhancing the design for environmentally friendly end products, creating more effective work systems, to make sure the safe operation of intricate systems that could cause catastrophes on an ecological and monetary scale, and utilizing community ergonomics. Zink, Steimle, and Fischer [46] extended the triadic model to show how current human factors initiatives have benefited sustainable development. Figure 5 shows the designing of human-centric ergonomics manufacturing and how ergonomics designs work to fit human capabilities by optimizing performance and contribute to mitigate health and safety issues. Ergonomics ensures to enhance the user experience by emphasizing importance of human elements during designing. Different components of the design process including task selection, tools, workstation layout, and designs of equipment must be in line with cognitive and physiological characteristics of the workforce.

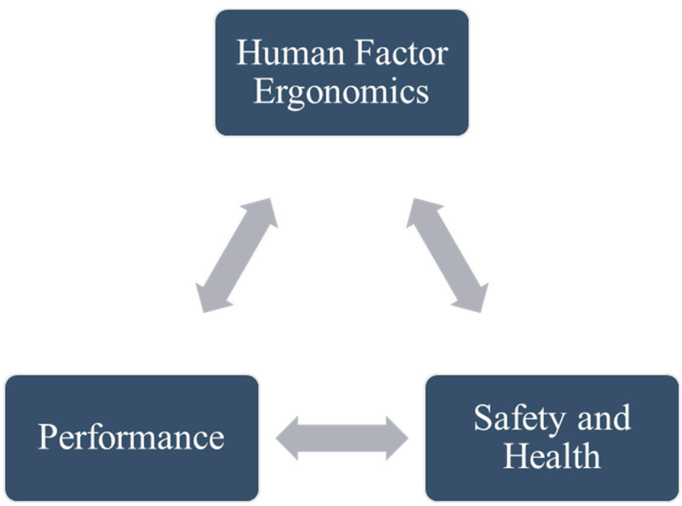

Figure 5. The designing of human-centric ergonomics manufacturing.

Ergoecology, eco-ergonomics, and green ergonomics are terms that frequently appear in the literature [47–49]. Green ergonomics, according to Thatcher [50], is concentrated on the reciprocal relationships between nature and human systems. This entails examining (1) how design ergonomics and relative assessment could be utilized to protect, regenerate, and conserve nature and (2) how different ecosystem services could be tapped to support the increased efficacy and well-being of human-based systems. No matter how well we try to define the breadth of the connection related to the human-based factor and sustainability for development, human traits, behavior, and engagements with technology remain the essential components of sustainable development strategies. To comprehend and improve the results of human–system interactions, there is a need to achieve a natural synergy linking these fields and ergonomics. The use of an ergonomic design approach when creating new products or altering existing ones aims to satisfy the needs of both the present users of the products in question or the actors who contributed to their creation as well as those of the products' potential customers and those who will be involved in the future manufacturing capabilities and processes. The utilization of ergonomic practices and requirements, as outlined in line with the human factors, enables end users to reach the necessary level of humanistic adjustment [51]. Furthermore, it must be emphasized that each product and the related method by which it is implemented influence the end users along with the surrounding area, the environment, and the stakeholders of the organization. Therefore, ergonomics should be viewed as a focused discipline for stakeholders. Figure 6 shows the relationship between the human factors, performance, and safety of workers. 5G stands for 5 Good Practices, 4M + 1D stands for Method, Men, Machines, Materials and Designs, 5W + 1H stands for What, Who, Where, Why, When and How, CAD stands for Computer Aided Designs, FEM stands for Finite Element Method, KPI stands for Key Performance Indicator, and KAI stands for Knowledge, Attitude, and Implementation.

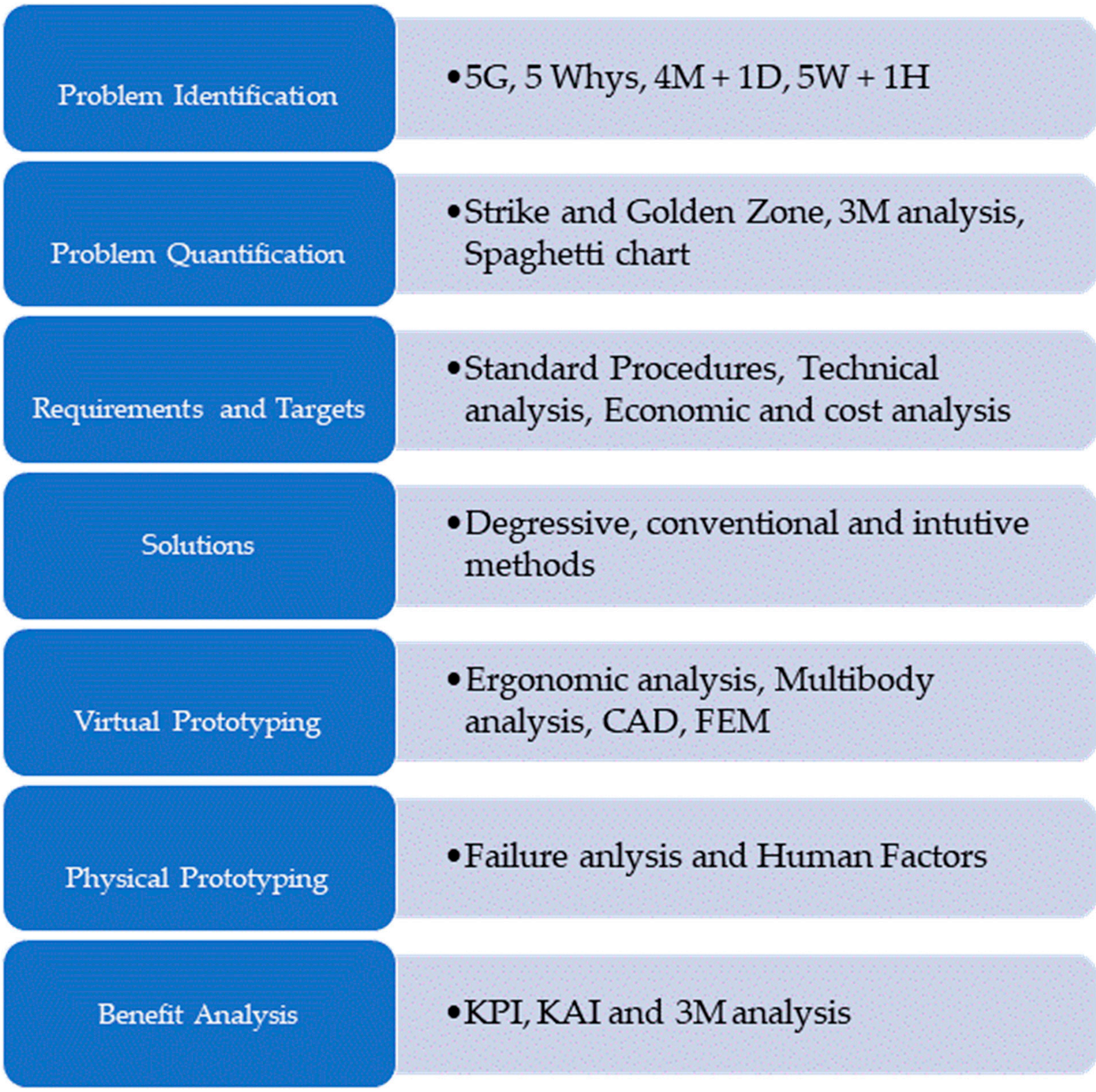

Figure 6. Role of human factors and ergonomics design on performance, safety, and health.

This section provides an overview of the manufacturing processes, including factors such as human factors, sustainable practices, Industry 4.0, information technology, and the role of ergonomics. This section provides key insights from the existing literature to understand the manufacturing environment. The literature ranges from academic journals, review papers, and conference proceedings to explore manufacturing industries and identify common trends and practices. The strategy of this review involves gathering information across the factors explained above, identifying common things, and analyzing the relationship between different factors of manufacturing and their broader implications.

4. Changes in Global Work Culture

There has been a sizable movement in the types of labor that are performed in various parts of the world as a result of changes in the global economic environment over the past ten years. These changes have taken place in both economically developed and economically advanced countries. In the past, developed economies have invested a lot in the production of mass-produced commodities. Within the context of the supply chain and the international economy, these nations have increasingly outsourced manufacturing and service activities to economically developing nations over the last two decades. This has caused a shift in the work performed inside economically developed countries toward a concentration on a service economy (including healthcare services), leading to a greater focus on the design of non-work systems like services for consumers and human–computer interactions [52]. Additionally, the promotion of innovation has led to an increase in the number of small-scale startups in some economically developed countries. Simultaneously, economically growing nations have increased their manufacturing base, leading to an increase in employment. As a result, the focus of employment has switched away from historically being dependent on local agriculture and more towards industrialization (often in the absence of the HFE benefits that are evident in economically advanced nations). Workers are paid little and work in unfavorable conditions. The cheap cost of goods production is leading to sharp increases in manufacturing. The number of low-wage service sector jobs is also growing in several of these economically emerging countries (e.g., call centers and banking services). At the same time, the informal sector employs the majority of workers in some nations [53], and agriculture continues to be the key industry driving the nation's economic growth [54], often even involving young children who work for little to no pay. In addition, the mechanization and automation of work systems are still on the rise, not only in the industrial sector but also in the service sector [55]. The connection between people and technology may evolve as a result of the introduction of additional technology and its greater capabilities (often beyond human capabilities).

Technology may influence work, but this frequently happens via side effects. For instance, the post-World War II Western World's goal of having more free time has not come to fruition. This is, in part, due to a rise in work intensity [52] that is being indirectly supported by technology. However, this is not only a case of technology taking the place of people at work (see airport counters or numerous shop checkouts) but rather a result of globalization. According to Friedman [56], this resulted from the fusion of three components, two of which are technological: quick and affordable communications and universal computer interfaces (another is the freedom of Asian and Eastern European countries to compete in the global marketplace). Construction of a huge fiber-optic communications system and its subsequent sale at highly discounted rates resulted in inexpensive communications as a result of economic overconfidence. The development of the universal computer interfaces resulted from intensive work on standards committees at all levels as well as extensive technical study, including ergonomics, at Xerox's PARC campus. Thus, the world of labor is altered by the interaction of technology and broader social forces, and this shift is not necessarily positive [57].

These modifications have resulted in the "period of intensive turnover from many existing work activities to new ones" that Bartlett observed. This is likely to always be the case if technological advancement occurs. It is a process that shows no signs of slowing; on the contrary, it appears to be accelerating [58]. However, they have also brought about changes in the nature of employment, such as extended working hours and globalization [59]. These same writers have also noted a simultaneous rise in part-time employment, which is happening primarily for social and economic reasons. Although most workers seem to prefer a "regular" work week of 35 to 40 h, there are an increasing number of options that are either longer or shorter. This is referred to as the Goldilocks Hypothesis, which was first proposed by Goldenhar et al. [60]. In a drastically altered society, we are still attempting to strike a balance between productivity and well-being (Bartlett's "human efficiency and health"). The "long bet that within a few years most operatives will be combining two or more jobs which have generally been regarded as different, and as requiring different performers" has come true, but not in the way planned. Instead of combining traits into one profession, an increasing number of people are choosing to work two jobs, usually for different employers.

Aside from technology, the three most significant developments in the world are population demographics, social interactions, and a growing concern for sustainability. As people travel across countries and regions, their preference for how many children they have has changed, and populations are no longer static if they ever were. These demographic shifts indicate that Western country populations are aging and becoming more racially and ethnically diverse [61,62]. The workforce as a subset reflects these developments as well as an increase in the number of people with disabilities and women working in traditionally male vocations. The trend is undoubtedly toward a greater diversity of job occupants from an ergonomics perspective. The sociotechnical systems direction of ergonomics has focused on designing work that satisfies both the social and financial demands of the workers, at least to some extent [52]. The necessity for social connection both inside and outside the workplace has been the focus of research and conjecture across the globe under the heading of "social capital" [63]. The last quarter of the 20th century saw "The Great Disruption" in social capital, with measures of social cohesion falling and indicators of social disruption rising in Western cultures, for instance, divorce rates and crime. Because of these developments, the workplace has become an even more significant social setting; however, we are now less devoted to powerful organizations like employers and unions. There have been some positive tendencies in more recent times, such as the micro-capital movement and the increased social capital production in local communities, activist activities, or neighborhoods [64]. Despite one of the primary research studies, Limits to Growth, sustainability is a notion that is finally becoming more widely understood by the general population. The 35-year-old Limits to Growth [65] has recently undergone a big update [66]. Overshoot represents a fundamental idea in sustainability that has a direct connection to ergonomics [67]. The idea was developed by Wackernagel et al. [68], who studied the effects of several important factors on the carrying capacity of the earth and discovered that we had achieved the full capacity for many of them by the 1980s. As a result of increasing expansion, a capacity constraint, and response time lags, we are currently in an overshoot situation. All of these characterize the modern world when time delays in individual, business, and governmental responses are painfully visible. Even in a paper that questioned sustainability in our context [69], temporal gaps were evident. In the future, as ergonomists, every decision we make will need to take into consideration how the impacts of that decision will affect sustainability.

The shift in global landscape is influenced by change in the economic conditions. The transition from mass production to a service-oriented economy, coupled with the outsourcing of manufacturing and service activities to economically developing nations. Three significant developments are shaping the world such as population demographics, social interactions, and sustainability.

5. Role of Ergonomics

Ergonomists currently deal with a variety of occupations: "Nothing can now stop an enormous and accelerating expansion of administrative, planning, arbitrating, and general management opportunities". Although it has never really gone away, information theory is no longer deemed to be relevant to manual skills; instead, we study and advance jobs that are considerably further up the skill/rule/knowledge ladder. Ergonomists frequently research management, planning, and other topics under the broad heading of decision making. In his observation that "the studies upon decision taking, as it is called, which have grown profusely in the last few years will attract more and more attention", Bartlett was entirely correct. With the development of Naturalistic Decision Making [70] and the ongoing application of Brunswick's Lens Model [71]—both of which predate Bartlett's paper—we now have well-established theories of decision making. Older ideas seem to hold up well, like work itself, despite the emergence of more current ones.

5.1. Effect of Physical Ergonomics on Performance

The physical and psychological elements are interconnected, share similar consequences, and are motivated by similar job circumstances. Physical ergonomics interventions heavily rely on psychological aspects [72]. Most studies have also combined the evaluation of physical and psychosocial components. As a result, we took into account physical along with psychosocial aspects for the physical ergonomic domain. The frequency, intensity, and duration of various physical workload and related factors, such as uncomfortable work stances, static postures, repetitive motion, physical porosity, noise and vibration, prolonged standing and sitting, lifting different heavy loads, and other environmental factors (noise, lighting, temperature, and humidity) that expose workers to the risk of Musculoskeletal Disorders (MSDs), determine the level of risk associated with physical factors [73]. Similar to other risk factors, the degree of exposure to psychosocial factors is influenced by characteristics including workplace stress, interactions with superiors and coworkers, job frustration, job insecurity, limited job control, job expectations, time constraints, mental burden, psychological strain, etc. Depression, cardiovascular disease, sleep issues, and other problems are caused by psychological variables that increase risk [74]. The frequency of MSDs among standing sewing machine operators in the lean textile sector was recently highlighted by Sakthi Nagaraj, Jeyapaul, and Mathiyazhagan [75], who also noted a substantial correlation between physical and psychosocial factors. The relationship between mental and physical factors that affect neck and shoulder problems, which negatively affect employees' activities and increase absenteeism, was also investigated by Widanarko et al. (2015) [76]. Physical and psychosocial aspects of work-related ill health harm individual and system performance, which has an operational impact on the organization. Some scholars have concentrated on ergonomics interventions to avoid the aforementioned effects and improve operational performance.

5.2. Organizational Ergonomics

Better worker performance and quality of life can be fostered through work design and managerial considerations in the field of organizational ergonomics. While management elements include communication systems, coworkers' support, supervisor assistance, and resource reduction, work design considerations include job rotation or diversity, independence, clear objectives, and time pressure. Job rotation is a key component of work design that distributes workers regularly to carry out a variety of tasks and permits them to swap jobs regularly. Job rotation has a favorable impact on physical aspects, such as preventing MSDs, but a negative impact on psychosocial aspects, such as employee contentment, health and safety, and intention to continue in the position [77]. However, by interacting with additional coworkers, job rotation fosters the expansion of professional knowledge, professional experience, and social support. The second fundamental component, job autonomy, provides employees the ability to decide how they want to schedule their time for work and to choose how they want to complete tasks [78]. However, Parker (2003) [79] found that the use of lean approaches, such as workflow formalization, assembly lines, and lean teams, has a detrimental impact on job autonomy. Workers who have job autonomy have the chance to complete a variety of activities, improving their performance and decision-making abilities. This makes it easier to see how certain characteristics of job design are converted into important organizational results. Time pressure, the third fundamental component, emerges when there is insufficient time to perform a task [78]. Time pressure affects all aspects of physical and psychological health due to the fundamental characteristics of lean production, such as the absence of buffers and continuous flow [74]. Time constraints cause physical demand and psychological strain during a task, which leads to failure on the part of the operator and a deterioration in system performance. Last but not least, job clarity refers to how well workers comprehend their own and their coworkers' responsibilities, goals, and working methods. Confusion and stress brought on by a lack of comprehension of their jobs negatively impact an organization's efficacy, QWL, and overall performance [80]. Additionally, Bray and Brawley (2002) [81] offered more proof that better job clarity improved operational effectiveness. The aforementioned debate and prior publications make it abundantly evident that there is a connection between operational performance and work design elements.

Management has significant controllable aspects that affect lean performance, such as the communicating systems, supervisor and coworker support including social support, and resource reduction. Information is transmitted to the respective employees of various departments via communication channels. To comprehend and analyze the performance and goals, management should communicate clearly with them, and workers should access feedback about those communications with their superiors. It is crucial to the success of lean deployment and performance to enable a swift and efficient transition to a longer-term, more sustainable lean aim. Lean fervently contends that two-way communication both exposes problems and offers solutions for them. Furthermore, communication is necessary to comprehend the work task and the team members' contributions [82]. Errors in communication cause confusion among employees and psychological stress. The performance of different workers or employees is also dependent on the managers and other coworkers. When communication is zero and interactions are bare minimum, it can lead to stressful situations for the workers, such as job burnout and lack of job satisfaction. The productivity, product quality, and improved worker cooperation of lean teams all contribute to the overall performance of the team. Better assistance from coworkers and managers, according to earlier research, not only reduces unfavorable outcomes but also improves employees' psychological health and productivity [83]. For instance, Sloan (2012) [84] found that improved support from coworkers and managers lowers employees' job fatigue. Additionally, Charoensukmongkol, Moqbel, and Gutierrez Wirsching (2016) [83] offered more proof of the link between social support and employees' job happiness, job burnout, and performance. To improve production flow and decrease idle time for people or machines, management must also engage in operations like reallocating workers or machines. Management must comprehend the effects these processes will have on employees and equipment. These resources include additional resources like tools and accessories in addition to labor and equipment. Reducing resources without taking into account the perspectives of the workforce affects risk factors for both physical and mental health. For instance, coworkers should accept the reallocation of a worker from a lean team because it may increase their physical and psychological demands. The proof was presented by Koukoulaki in 2014 [74] after reviewing 20 years' worth of research on the effects of lean on employees' physical and mental health. He concluded that cutting back on resources causes stress in the workplace, and he discovered that Just-In-Time (JIT) lean techniques, which are linked to cutting back on both resources and cycle time, had the largest correlation with stress. Figure 7 shows human-based design and working environment for increased efficiency to achieve the objectives.

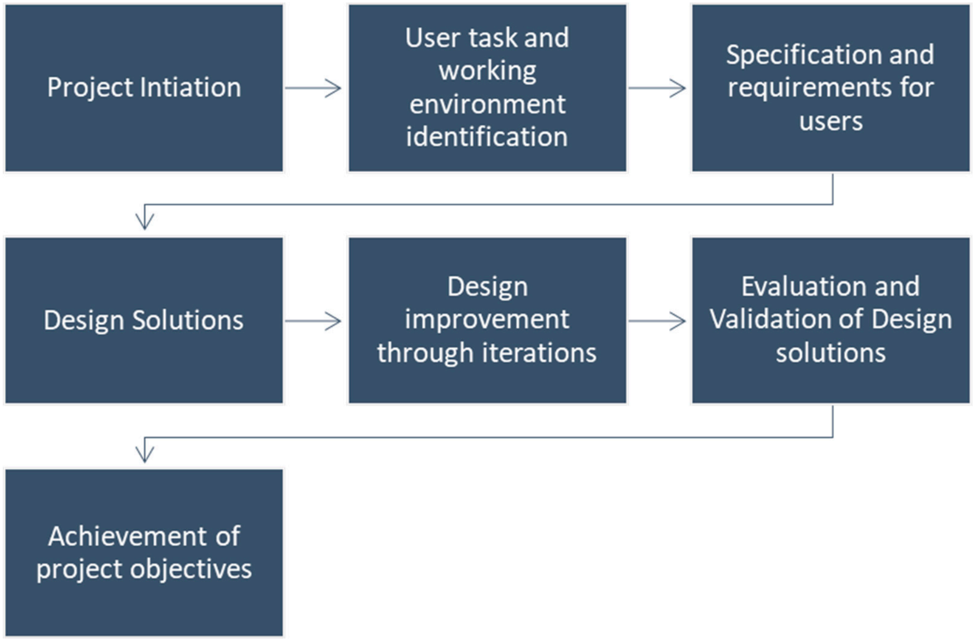

Figure 7. Human-based design and working environment for increased efficiency to achieve the objectives.

The role of ergonomics in the contemporary workforce highlights its involvement in various occupations and the evolving nature of work. This emphasizes the expansive opportunities in administrative, planning, arbitration, and general management roles.

5.3. Cognitive Ergonomics

Operational success is positively correlated with some cognitive variables, including situation awareness, human reliability (human error), and decision-making abilities [85]. For instance, Falck and Rosenqvist (2012) [86] found that poor ergonomics associated with cognitive tasks lead to faults and waste. Additionally, they showed a connection between cognitive demands (assembly complexity) and the quality of the final product and the production process. An experimental investigation performed by Falck, Ortengren, and Rosenqvist (2014) [87] found that poor cognitive ergonomics (complexity) greatly increased errors and waste during the assembly process. However, these research studies only paid attention to one component of cognitive ergonomics—complexity—while ignoring other factors, including motor reaction, reasoning, memory, and perception. Loft et al. (2018) [88] found that performance differed between-person degrees of situation awareness for a simulated submarine track management task, independent of the manufacturing context. The task accuracy, which included the closest point of approach, dive, and contact classification, was higher for operators who exhibited a higher average situation awareness than it was for operators with lower situation awareness. Better human reliability means that a task is consistently completed without error. Similar to the lean principle of doing things properly the first time, error-free activity leads to higher-quality processes or products. Effective and timely decision-making reduces the prevalence of errors arising during the process of performing complex tasks. Additionally, Park, Jung, and Kim's research (2020) [89] found that human reliability has a considerable impact on workers' productivity in a nuclear power plant. According to Tajri and Cherkaoui (2015) [90], the application of lean practices leads to stress associated with cognitive assessment, quantitative and qualitative overload (complexity), an unrestricted demand on versatility and competence, collective work, and cutting room work, which harms an organization's performance. When developing lean procedures, they took into account cognitive ergonomics to reduce stress. It is evident that a holistic consideration of cognitive ergonomics, encompassing various facets, is critical for optimizing operational success in diverse work environments.

6. Sustainable Manufacturing

As explained by NACFAM (National Council for Advanced Manufacturing USA), sustainable manufacturing is described as the production of manufactured goods using non-polluting, energy and resource efficient processes that are secure for workers, consumers, and communities [91]. The importance of sustainability in manufacturing is highlighted by global drivers, both as a means of reducing the effects of the drivers and due to the material and energy consumption of present production processes. The overall conclusion is that all countries must transition from a "Linear Economy", which involves resource extraction and disposal, to a "Circular Economy", which emphasizes recycling and little extraction and disposal, along with resource efficiency. All economic sectors, including manufacturing, are affected by this. It is important to note that other industries will use the results of manufacturing to transform their linear processes into circular ones. This is another reason why this study focuses on manufacturing.

Recycling/reuse involves the following:

- Re-use is the act of redeploying a product without refurbishing it; for example, taking mobile phones that have become "obsolete" in developed nations and redistributing them for sale in less developed nations.
- Remanufacturing involves returning a product to its initial state of manufacture. As an illustration, caterpillar runs a profitable engine remanufacturing company.
- Cascaded use involves utilizing a product for a lesser value purpose; for instance, converting worn clothing into pillow stuffing.
- Recycling involves removing a product's raw materials and repurposing them to make new items; examples include the frequently used materials steel and aluminum.
- Recovery is the practice of repurposing a product's components for low-value applications like road base.

Sustainability strongly depends on product design as well; "design for disassembly" is a key tenet, especially in connection to autos and other products where disassembly poses risks [92]. Table 1 shows various factors for future sustainable manufacturing. The global trend for sustainability in manufacturing is followed by the need to mitigate the impact of global drivers and address resource and energy consumption by optimizing them.

Table 1. Factors for sustainable manufacturing practices.

Time	Focus Point	Factors to Focus
Conventional Manufacturing	Economical Sustainability	• Economic benefits • Cost-effective manufacturing • Economic impacts • Market analysis
Present Manufacturing	Environmental Sustainability	• Emissions • Material recycling
Future Manufacturing	Social Sustainability	• Work ethics • Work environment • Health and safety • Community relationship • Human rights

7. Industry 4.0

Industry 4.0 represents the combination of ergonomics, human factors, and sustainability principles. A standard commercial supply-chain strategy is used in the manufacture of automobiles, where the dominant partner—typically the one who assembles the vehicle at the end of the chain—mandates that component prices decline by 3% annually for the duration of the contract without any negative impact on quality to boost the sustainability of the manufacturing. As a standard response to all of these demands of ergonomics and sustainability, incremental process improvements have been combined with sporadic, usually pre-planned upgrades to both processes and products [93]. Both of these responses have been based on sound engineering and management principles, with a dash of sound tacit knowledge from the workers. However, the additional limitations brought about by the requirement to meet sustainability's lowered energy and emissions demands suggest a sizable movement toward greater, more precise management of products and processes [94].

New manufacturing concepts, like the fractionated, networked factory that is geographically dispersed as well as novel technologies like additive manufacturing, cyber-physical systems for sensing and control, and new materials like graphene, alloys, and ceramics, all contribute to greater control. It should be highlighted that all of these will involve numerous knowledge contributions of various forms from numerous stakeholders. Table 2 explains the tools used in ergonomic manufacturing [95].

Table 2. World-class manufacturing tools and methods for ergonomic and sustainable manufacturing designs in Industry 4.0.

Tools and Methods	Explanations
5W + 1H	Problem analysis by going through the fundamentals of manufacturing. It involves the collection of requirements for problem-solving. 5W corresponds to questions such as What? Who? Where? Why? Where? While 1H corresponds to How?
5G	5G is the process to analyze factors such as failures, defects, malfunctions, breakdowns, and identification of irrelevant and non-functioning additions.
5 Whys	This method involves the identification of problems and relevant solutions through a series of questions involving Why.
4M + 1D	This method identifies the important factors for any manufacturing technique. Factors and sub-factors are analyzed for any process. The method involves Method, Men, Machines, Materials and Designs for any process.
Human error root cause analysis (HERCA)	Analysis of human performance in any manufacturing process to identify problems. Problems can be technical, procedural issues, human factors etc. Interviews with respective operated are conducted to find out the root causes of issues and problems.
The way to teach people (TWTP)	The process is used to assess the knowledge of machine operators in the process to know more about products, procedures, and equipment.
MUDA	This analysis is used to significantly reduce and eliminate the irrelevant activities performed by the operators in the manufacturing process.
MURI	This is an ergonomic analysis to identify the high-risk movements and positions for operators.
MURA	This analysis is used to identify the movements and processes that involve variable time. This analysis assists in standardizing the operation time for a particular process or procedure in manufacturing.
Strike and Golden Zone	A detailed analysis of work operations to minimize the movement of operators to overcome factors such as fatigue and ergonomic risks.
Spaghetti Chart	It is used to quantify and visualize the movements of machine operators through graphic imaging to ensure smooth operations.

Additive Manufacturing and Participatory Ergonomics

In contrast to subtractive manufacturing, which removes undesirable material from an ingot to leave the finished product, additive manufacturing refers to what has previously been referred to as "3D printing", in which the method uses the lowest amount of material possible to make the end product [95]. Minimizing the material used affects the complexity of the parts that may be manufactured, reduces the energy consumed in their production, and the relative ease of generating customized parts for individual users. These are considered the primary benefits of additive manufacturing [96]. The technique is most cost-effective for small quantities of components. However, there are still significant knowledge gaps for the successful, cost-effective application of this technology, and accurate surfaces on a component will likely require additional machining. Participatory ergonomics (PE) involves the use of participative methodologies and other forms of workplace participation to boost the efficiency of additive manufacturing [97].

According to Wilson [98], participation in ergonomics projects concerns the involvement of people in planning and controlling a significant amount of their work activities, with sufficient knowledge and power to influence both processes and outcomes to achieve desirable goals. Disparities in the implementation of PE projects can be observed between the USA and Europe. PE is frequently used in the USA to create and execute technology at the macro-ergonomics level. The fundamental element in the application of PE techniques to ergonomic solutions in Europe has been the inclusion of all project stakeholders. PE is a developing strategy that has progressed from the initial conceptual formulation and isolated applications to include implementation and evaluation. Although a participatory method is typically perceived to be advantageous, it has been noted that there is "often a lack of quality evaluation" and that there were few reports from projects that had received little or no benefit from participatory treatments. The fact that practitioners are hesitant to reveal obvious failures could be one explanation for the current lack of publications in this field. There could be two reasons for the paucity of high-quality assessments. First, if the project's outcome has not been favorable, the corporation will be less interested in reviewing it. Second, if a project is successful, a corporation does not perceive the need for evaluation. Additionally, there may have been a large reorganization inside the corporation in this instance, which may have limited the use of a pre/post-evaluation technique [99].

Liker et al. [100] analyzed and contrasted the PE programs of two Japanese and two American production plants. The restructuring of repetitious manufacturing jobs to minimize physical strain on employees was a key component of all four programs. In both countries, the programs were successful in causing a sizable number of job transfers, but there were some variances in the structure and participation procedure. Participation in the Japanese cases was a meticulously monitored procedure employing quality circles. Multilevel task forces with high levels of autonomy and group decision-making were established in the USA. Both programs were successful, indicating that different PE approaches may be required in various cultural contexts. Halpern and Dawson [101] created and implemented a PE program to regulate and lower workers' compensation costs for sewing machine operators at a company that manufactured automobile products. The program was divided into three main sections: organization, ergonomics tools and methods, and job design concepts. The vice president appointed a management steering group, on which the engineering manager, plant manager, safety director, and a consultant ergonomist served as members. Supervisors, maintenance workers, and operational staff formed a second committee. A second group within the human resources division launched a similar attempt to reduce the severity of ailments and injuries by creating better case management and medical intervention programs. The intervention program included task analysis for a set of six sewing jobs that led to the redesign of micro workstations, such as the ability to choose between sitting or standing, sewing tables that could change in height to improve line of sight, supports for workers' forearms, ergonomically shaped and padded edge workstations, foot pedal redesign, a machine guide, and modified scissor designs. The process flow was reviewed to include short breaks (and a stretching regimen), and new production procedures based on ergonomic principles were designed for new items to make them easier to manufacture. Over four years, there was an approximate 85% decrease in the number of MSD claims and a 42% decrease in overall compensation expenses. In two electrical sectors, St Vincent et al. sought to implement and validate a PE procedure. After receiving initial training and analyzing several working scenarios, joint ergonomics groups (workers and technical representatives) produced 50 implemented recommendations. These included reexamining the workflow (material movement, the addition of carts and pallet raisers, etc.), redesigning the workstations (seating position, height, etc.), investing in new tools and installing balance systems for older ones, automating some processes, and lengthening the work cycle to provide the operator longer to complete the task. Risk factors were reduced by 78% in three of the task categories, including postural stress, force requirements, and mechanical stressors. Table 3 explains the methods for participatory ergonomics.

Table 3. Methods used for participatory ergonomics.

Methods	Description
Problem Assessment and Analysis	Activity and link analysis
Idea and Solution Generation	Analyzing the problem for possible solutions
Idea and Solution development	Design analysis, scenario building, group discussions, and focus groups
Solution Evaluation	Modelling, layouts, and new checklists
Implementation and Support	Analyzing results

8. Use of Information Technology

As an example of the use of information technology, the Federal Republic of Germany (FRG) has created a networking-based initiative called "Industrie 4.0". There is a broad hypothesis that manufacturing is entering its fourth generation that includes sustainability and HFE. The first generation saw the introduction of steam and mechanical production (a technical revolution), which was preceded by the shift to standard parts, mass production, and task specialization (an organizational revolution), which was then followed by the introduction of IT (again a technical revolution), which will be followed by the networking revolution. The latter stage involves the "Internet of Things" (IoT), which includes data, services, and cyber-physical systems (CPS) [102]. All these modern tools not only help in achieving sustainable manufacturing but also aid to integrate HFE.

Virtual objects may be nothing more than data stores; however, they can also include processing power. For instance, software systems can be embedded into devices to enable them to communicate with the Internet, virtual objects, and other humans. They may be given extensive learning skills to allow them to achieve even greater autonomy, as well as additional processing power to adapt to changes in the environment (such as autonomous vehicles) [103]. These characteristics of autonomy and education are even more relevant to the composite virtual objects (CVOs). At this level, substantial software resources may be available that connect sensors and actuators, supervise the behavior of the virtual objects within the CVO, interact and negotiate with other CVOs, and derive strategy from the workings of the Business Application Suite. The software community refers to these processes as "middleware". In a stable environment, rule sets created during the design and implementation process for the CVO may be used to guide the middleware's decisions. It is more likely that artificial intelligence and machine learning will play a big role in a dynamic, non-repetitive setting, probably with some human user intervention [92].

When a business application suite combines CVOs, the result is a simple CPS that requires human interaction but performs the majority of tasks automatically and with a high degree of autonomy. This enables the strategic goals of an entrepreneur to be transformed into sequences of required behaviors. Table 4 explains the role of information technology.

Table 4. Role of information technology in system ergonomics.

Roles of Information Technology	Description
Processes and Objectives	Business objectives Business Strategy Effective use of information technology Optimization of processes using information technology tools
Information services	Development of a new knowledge base Models based on real-time data Data collection and analysis
Networking	Network development Global connectivity

9. Retraining Workforce

National initiatives that are similar to the FRG's Industrie 4.0 program (for instance, the UK's Future of Manufacturing and France's La Nouvelle France Industrielle) place a strong focus on the value of people for HFE and sustainability of manufacturing environment. Jobs will change as a result of novel strategies in business models, enterprise networks, new materials, and/or new processes; however, these adjustments will not substitute human qualities like real-world knowledge, intellect, and experience, nor will they replace the ability to remain resilient when faced with both anticipated and unforeseen change. They do highlight the value of specific IT abilities, particularly in modelling and simulation, problem-solving, dispersed teamwork, and similar areas. Managers, operators, professionals, and apprentices must have access to these talents throughout the organization. This seems to be an implicit admission that switching to the network would not solve all of your problems; it may only fix some of them, but it will likely redistribute the rest and possibly create some new ones [92]. The role of HFE for sustainable manufacturing will not decrease with the incorporation of the latest technologies.

10. Role of Ergonomics in Designing Jobs

The drive to CPS and the IoT comes with a large reliance on modelling and simulation, which poses a unique problem. The distributed nature of manufacturing that is envisioned suggests that the formal and tacit knowledge required to safely and effectively manufacture safe, functional, and cost-efficient goods will also be distributed [104]. While certification may offer some measure of assurance regarding what is produced and how it is produced, it is all but certain that legally and professionally required verification and validation (V&V) of products and processes will have to be carried out by modelling and simulation—an evolution of what is already becoming common in manufacturing. The majority of the parties engaged will need to do this because the CPS could alter at any time; it won't only be engineers and business planners. This suggests that V&V will represent an ongoing process. Thus, the modelling and simulation of this virtual manufacturing environment, as well as of the expected interactions and perceptions of the end users, will turn into a crucial tool for knowledge acquisition, application, and training and effective, efficient everyday operations. The capacity to interface with managers, employees, and support staff within an organization to learn and retain their skills and, thereby, increase their employability will become a critical component of the systems ergonomists' expertise [105].

Second, given the likelihood of manufacturing changes, these challenges have greater importance. Workers will feel less involved in their work as a result of the tighter control over processes that will likely come from and be allotted to CPS. This separation is likely to increase as virtual objects and CVOs grow more independent and unavoidably acquire learning capabilities. The fragmentation of the factory into a network, which most likely will remove any visibility of the continuity and integrity of the entire process, will make this distance from work even more pronounced. Both of these have an impact on contextual awareness and eventual comprehension [106]. Third, because the pace of change is accelerating due to both the longer-term requirements of the sustainability agenda and the shorter-term drivers of competitive advantage (particularly concerning "mass personalization", i.e., "no two products are the same"), there is a problem with "human workability". Human workability is defined as people and teams having the physical, mental, emotional, and social functional capacity to carry out specific tasks, as well as the professional competence, principles, ethics, and knowledge of work environments, work communities, supervision, and the traits and processes of change [105].

The demands of workplace resilience, such as the need for individualized products, problem-solving skills, and quick adjustments to production schedules, will necessitate prompt communications. IT tablets (or comparable devices) can be expected to play a significant part in providing mobile real-time situation awareness, which is a requirement for resilience [107]. This awareness will be used to notify operators, support their tasks, and offer quick feedback. The architecture of the IT infrastructure to support such jobs and their supporting tools will be significantly impacted. Even for minor issues, it is probable that communication across a worldwide network will be necessary for problem-solving. As a result, most of the ergonomics research already done on computer-supported cooperative working will apply to this, albeit it could need a little updating. Furthermore, if such procedures are to be successful, it is clear that a knowledgeable, empowered workforce with solid connections is required.

Fourth, "workability" in the context of change necessitates taking "employability" into account. This encompasses a person's capacity to find and keep a job, to change positions within an organization, to find new work in a position that is comparable to their current one, and to have the knowledge and skills necessary to do all of these things. Employers play a role in guaranteeing collective learning because the latter is true for all employees; it turns into an organizational skill, especially when it comes to teaching sustainability skills. People may acquire these abilities at work, but the critical thinking required can be applied elsewhere in life. Because knowledge work is valued more highly in this new industrial environment, there may be a noticeable decrease in the number of jobs available for managers and semi-skilled workers. As a result, it will be crucial to ensure that they are marketable in other fields, professions, and roles.

Fifth, it is important to integrate the concepts of responsible research and innovation into daily duties and roles to fulfil the principles of corporate social responsibility [108]. The principles must first be transformed into Key Performance Indicators (KPIs) that reflect the organization's performance in accordance with these principles, and these must then be cascaded down into the activities (i.e., Activity Performance Indicators—APIs) that employees carry out within their positions. They may need to be included in the Minimum Critical Specification for a function following the sociotechnical concepts put forth by Cherns and others [109,110]. Because of this, the role-holder will need training and access to resources to implement these APIs. Given the variety of forms these APIs may take, the organization may need strong connections to nearby educational and training institutions, as well as professional services, to fulfil its commitments to the role-holder. The complexity of all the aforementioned problems stems from the fact that every person is unique in their goals, objectives, and past experiences, according to an ergonomics perspective. There will need to be some rethinking of what ergonomists typically refer to as "work design", which emphasizes health, safety, satisfaction, and performance.

11. Discussions

The review explores the relation of ergonomics, sustainable manufacturing, and integration of Industry 4.0 principles. The findings of this review paper explain the role of human factors and ergonomics in shaping modern manufacturing in Industry 4.0. The analysis of different studies assists to understand the relationship between cognitive ergonomics and operational success, with the focus on factors such as situation awareness, human reliability, and effective decision-making. The analysis drawn from various studies such as the broader assessment of situation awareness in simulated tasks by Loft et al. [88], enables the broader understanding of cognitive ergonomics. The review analyses the impact of cognitive abilities of human-centric designs such as decision making and situational awareness on operational success. While evaluating cognitive ergonomics, there are certain complexities and limitations to accurately quantify and improve these factors. Situational awareness in complex work environments poses challenges for accurate assessment and intervention. Similarly, biasedness and uncertainties cannot be eliminated from decision-making processes.

The successful transition to sustainable manufacturing needs a paradigm shift in the industries. Sustainable manufacturing needs a combined approach of the circular economy using the recycling, re-use, and remanufacturing approach for sustainable production. The outlined factors in this review for sustainable manufacturing practices range from economical to social sustainability and provide a comprehensive analysis for industries to align with emerging global trends. There is a need to balance economic efficiency, social equity, and sustainability, and certain limitations emerge due to the complex nature of all these factors and require robust solutions for appropriate focus on each one of these factors.

Furthermore, the integration of Industry 4.0 highlights the importance of ergonomics, human factors, and sustainability principles. The evolution of manufacturing technologies, from incremental process improvements to the adoption of novel technologies like additive manufacturing, cyber-physical systems, and advanced materials, is a pivot point of this paradigm shift. The discussion on tools and methods for ergonomics manufacturing in Industry 4.0, as outlined in Table 2, can be used as a practical guide for industries that are trying to adopt these changing trends. The section on additive manufacturing and participatory ergonomics analyzes the potential benefits of 3D printing and emphasizes the need for participative methodologies to enhance efficiency. Wilson's [98] perspective on participatory ergonomics highlights the importance of involving the workforce in planning work activities, the same perspective resonates in the work analyzed by Liker et al. [100] and Halpern and Dawson [101].

Information technology is a powerful tool that can enable sustainable manufacturing as shown by Industrie 4.0 initiative by Germany. The discussion on virtual objects, composite virtual objects, and their reliance on middleware emphasizes the vital role of information technology in shaping the future manufacturing industry. The emphasis on IT abilities, modelling, simulation, and dispersed teamwork increases the need for a diverse and versatile workforce that can navigate the complexities of technological advancements. Ergonomics plays an undeniable role in designing jobs and aligning with the shift toward CPS and the IoT. However, there is a need to navigate the challenges posed by distributed manufacturing by implementing verification and validation through modelling and simulation. There is no doubt about the transformative and revolutionary potential of IT to enable sustainable manufacturing, but it comes with certain implications that require critical assessment. While IT provides better human–computer interaction and process automation, it raises issues regarding digital literacy, data privacy, and technological dependency.

The integration of research and innovation further emphasizes the urgent need for a holistic approach by incorporating human factors in manufacturing systems. By integrating cognitive ergonomics, sustainable manufacturing, Industry 4.0, and information technology, we can foresee a future with human factors playing a pivotal role in shaping efficient and socially responsible manufacturing processes.

12. Conclusions

This review provides a detailed analysis of human factors and ergonomics in sustainable manufacturing and the global work force. The review discussed principles of ergonomics and its evolving role in the era of Industry 4.0. The effective use of human capabilities, limitations, and behavior can significantly enhance process efficiency. This review intends to promote the human-centered design for sustainable manufacturing processes that include problem identification and objective evaluation to achieve maximum efficiency. Traditional HFE studies have focused on economic aspects, leaving a gap in the consideration of social and ecological dimensions. A paradigm shift is necessary, urging HFE to actively pursue the fulfillment of all three major components of sustainability. The review highlights the importance of understanding and adapting to the evolving nature of work systems, embracing Industry 4.0 technologies, and addressing the socio-demographic shifts in the workforce. The review analyzes the relationship between cognitive variables and operational success by examining the impact of cognitive ergonomics on tasks such as decision making, situation awareness, and human reliability and how these cognitive factors contribute to enhanced productivity and reduced errors in complex work environments. The review further highlights the role and importance of sustainable manufacturing to overcome ecological and economic challenges. Modern IT infrastructure and the use of advanced technologies in additive manufacturing are critical factors to achieve better control over products and processes. The evolution of global work culture, the use of cognitive ergonomics, and the potential of Industry 4.0 can collectively shape the future of HFE.

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