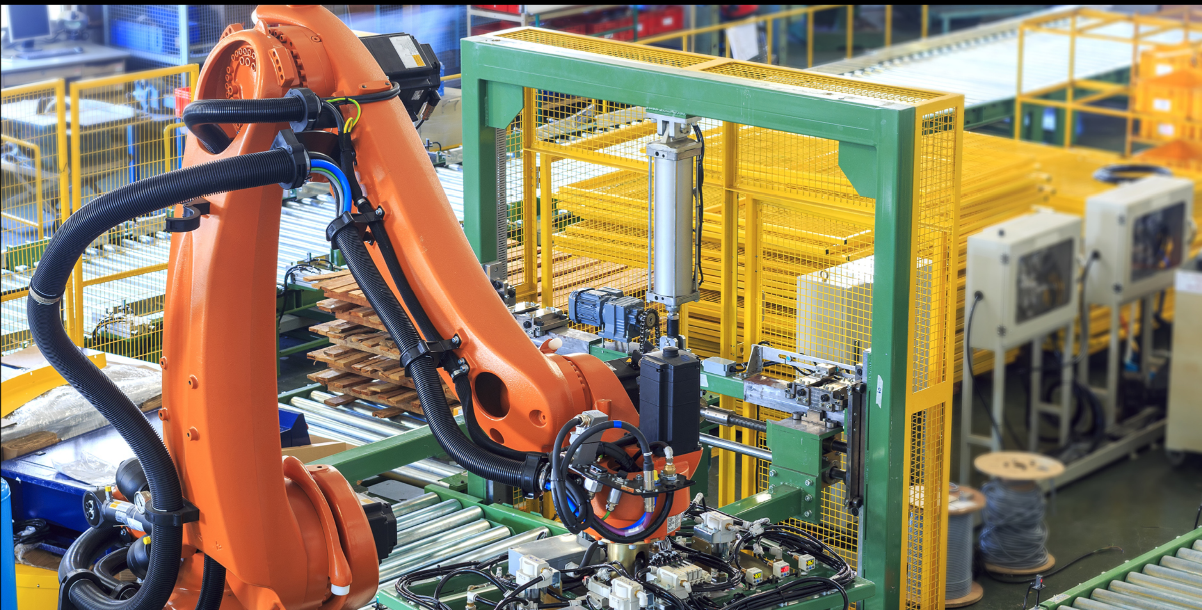
Handbook of Smart Manufacturing

Forecasting the Future of Industry 4.0

EDITED BY

Ajay, Hari Singh, Parveen,
and Bandar AlMangour



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Handbook of Smart Manufacturing

This handbook covers smart manufacturing development, processing, modifications, and applications. It provides a complete understanding of the recent advancements in smart manufacturing through its various enabling manufacturing technologies, and how industries and organizations can find the needed information on how to implement smart manufacturing towards sustainability of manufacturing practices.

Handbook of Smart Manufacturing: Forecasting the Future of Industry 4.0 covers all related advances in manufacturing such as the integration of reverse engineering with smart manufacturing, industrial internet of things (IIoT), and artificial intelligence approaches, including artificial neural network, Markov decision process, and heuristics methodology. It offers smart manufacturing methods like 4D printing, micro-manufacturing, and processing of smart materials to assist the biomedical industries in the fabrication of human prostheses and implants. The handbook goes on to discuss how to accurately predict the requirements, identify errors, and make innovations for the manufacturing process more manageable by implementing various advanced technologies and solutions into the traditional manufacturing process. Strategies and algorithms used to incorporate smart manufacturing into different sectors are also highlighted within the handbook.

This handbook is an invaluable resource for stakeholders, industries, professionals, technocrats, academics, research scholars, senior graduate students, and human healthcare professionals.

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Contents

Preface

Smart manufacturing is a broad category of manufacturing that employs computer-integrated manufacturing, high levels of adaptability and rapid design changes, digital information technology, and more flexible technical workforce training. Other goals sometimes include fast changes in production levels based on demand, optimization of the production system, efficient production, and recyclability. This book is expected to provide the compiled smart manufacturing knowledge to the involved stakeholders from users in the industry to the academics and researchers. The detailed description of various smart manufacturing techniques like 3D printing, 4D printing, and approaches that makes manufacturing digital such as Industry 4.0 techniques are included in this book along with various smart materials like polymers, metals, ceramics, composites, biomaterials, biodegradable materials, responsive materials, functionally graded materials, and various applications of smart industries. In addition to above various case studies of smart manufacturing specially related to production, mechanical, industrial, computer science, electronics engineering, and biomedical are covered to help undergraduates, postgraduates, and research scholars. This compilation will bring to its readers the latest developments/advancements in smart manufacturing, which is currently not available at one place. This book will bridge the gap between R&D in smart manufacturing and professionals.

This book is an outcome of the extensive research accomplished by various researchers, academicians, scientists, and industrialists in smart manufacturing. The area is under-explored and the outcomes are worth the research effort. Experimentation, modeling, characterization, and simulation techniques are the powerful tools for developing new concepts, approaches, and solutions to devise valuable information on the process which led to need of compiling this work. Since, the information related to smart manufacturing is scattered into patents and research publications and not at one place in a systematic form, editors recognize their ethical responsibility to compile, share, and spread the knowledge accumulated and technology developed, with the students, researchers, and industry people, to draw the benefits of this work in the form of a book and gain technical competence in the frontal area.

The book consists of 18 chapters that describe perspectives of smart manufacturing with Industry 4.0 aspects. "Smart Manufacturing and Industry 4.0: State-of-the-Art Review" determines the dimensions that help in implementing smart manufacturing in the I4.0 environment in SMEs. "Study and Analysis of IOT (Industry 4.0): A Review" provides an overview of analysis of IOT adaptation effect in past and present industries. "Recent advances in Cybersecurity in Smart Manufacturing Systems in the Industry" discusses advances in the security of smart manufacturing systems, strengths and weaknesses of the manufacturing systems, existing threats, and preparedness for future cyber-attacks. "Integration of Circular Supply Chain and Industry 4.0 to Enhance Smart Manufacturing Adoption" focuses to develop a framework based on the Fuzzy Analytical Hierarchy Process (FAHP), one of the multi-criteria decision-making methods (MCDM), which computes and assigns weights to each identified circular supply chain practice within an industry. "Artificial Intelligence with Additive Manufacturing" summarizes the role of artificial intelligence in additive manufacturing in a manner to show how innovative additive manufacturing plays a role in today's industry. "Robotic Additive Manufacturing Vision towards Smart Manufacturing and Envisage the Trend with Patent Landscape" foresees robotic additive manufacturing in various aspects covering basic system step to futuristic vision. "Smart Materials for Smart Manufacturing" demonstrates the various kinds of smart nanomaterials and their advantageous properties in both historical and future applications. "Smart Biomaterials in Industry and Healthcare" explores smart materials for bringing advancement in biomedical engineering and other industrial applications. "Ferroelectric Polymer Composites and Evaluation of Their Properties" presents the results of a study of ferroelectric polymer composites with a high permittivity. "4D Print Today and Envisaging the Trend with Patent Landscape for Versatile Applications" analyzes the future trend with the aid of patent landscape analysis. "Investigating the Work Generation Potential of SMA Wire Actuator" aims to develop an elementary mathematical model of an SMA wire actuator in biasing conditions on the SIMULINK platform while including the traveled path history of SMA material and thereby, carries out a parametric study that determines the most influencing parameter that affects the work generation capability of wire actuator. "Troubleshooting on the Sample Preparation during Fused Deposition Modeling" deals in-depth with the challenges and issue during the printing and suitable solution for better print quality. "Hybrid Additive Manufacturing Technologies" focuses to produce and compare research studies on the different hybrid additive manufacturing processes. "Smart Manufacturing Using 4D Printing" deals with the concepts and regulations governing 4D printing, along with the materials utilized, applications, and obstacles that still need to be removed. "Developments in 4D Printing and Associated Smart Materials" provides a brief overview of 4D printing processes using various composites and intelligent materials including smart materials, and shape memory alloys. "Role of Smart Manufacturing Systems in Improving Electric Vehicle Production" explores the current market need for manufacturing that closely relates to an electric vehicle and develops a structural framework that utilizes the interpretative structural modeling approach and MICMAC approach to achieve the objective. "Safety Management with Application of Internet of Things, Artificial Intelligence, and Machine Learning for Industry 4.0 Environment" evaluates the major issues regarding health and safety integration with the Industry 4.0 revolution. "CPM/PERT-Based Smart Project Management: A Case Study" optimize the design and installation time of the 8-megawatt power plant to be built for a cement factory in Barbados.

This book is intended for both the academia and the industry. The postgraduate students, PhD students, and researchers in universities and institutions, who are involved in the areas of smart manufacturing with Industry 4.0 perspectives, will find this compilation useful.

The editors acknowledge the professional support received from CRC Press and express their gratitude for this opportunity.

Reader's observations, suggestions, and queries are welcome,

Dr. Ajay
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The editors are grateful to the CRC Press for showing their interest to publish this book in the area of smart manufacturing and Industry 4.0. The editors express their personal adulation and gratitude to Ms. Cindy Renee Carelli (Executive Editor) CRC Press, for giving consent to publish our work. She undoubtedly imparted the great and adept experience in terms of systematic and methodical staff who have helped the editors to compile and finalize the manuscript. The editors also extend their gratitude to Ms. Christina Graben, CRC Press, for support during her tenure.

The editors wish to thank all the chapter authors for contributing their valuable research and experience to compile this volume. The chapter authors, corresponding authors in particular, deserve special acknowledgments for bearing with the editors, who persistently kept bothering them for deadlines and with their remarks.

The editors, Dr. Ajay, Mr. Parveen and Dr. Bandar AlMangour, wish to thank Prof. Hari Singh for his unreserved guidance, valuable suggestions, and encouragement in nurturing this work. Prof. Hari Singh is a wonderful person and the epitome of simplicity, forthrightness, and strength and is a role model for editors.

Dr. Ajay also wishes to express his gratitude to his parents, Sh. Jagdish and Smt. Kamla, and his loving brother Sh. Parveen for their true and endless support. They have made him able to walk tall before the world, regardless of sacrificing their happiness and living in a small village. He cannot close these prefatory remarks without expressing his deep sense of gratitude and reverence to his life partner, Mrs. Sarita Rathee, for her understanding, care, support, and encouragement to keep his morale high all the time. No magnitude of words can ever quantify the love and gratitude the he feels in thanking his daughters, Sejal Rathee and Mahi Rathee, and son Kushal Rathee who are the world's best children.

Finally, the editors obligate this work to the divine creator and express their indebtedness to the "ALMIGHTY" for gifting them power to yield their ideas and concepts into substantial manifestation. The editors believe that this book would enlighten the readers about each feature and characteristics of smart manufacturing and Industry 4.0.

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Editor's Biography

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He has organized various national and international events, including an international conference on Mechatronics and Artificial Intelligence (ICMAI-2021) as a conference chair. He has more than 20 national and international patents to his credit. He has supervised more than 8 MTech, PhD scholars, and numerous undergraduate projects/ thesis. He has a total of 15 years of experience in teaching and research. He is a guest editor and review editor of the reputed journals including Frontiers in Sustainability. He has contributed to many international conferences/symposiums as a session chair, expert speaker, and member of the editorial board. He has won several proficiency awards during the course of his career, including merit awards, best teacher awards, and so on.

He is adviser of the QCFI, Delhi Chapter student cell at JECRC University and has also authored many in-house course notes, lab manuals, monographs, and chapters in books. He has organized a series of Faculty Development Programs, International Conferences, workshops, and seminars for researchers, PhD, UG, and PG students. He is associated with many research, academic, and professional societies in various capacities.

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Mr. Parveen is currently serving as an assistant professor and head in the Department of Mechanical Engineering at Rawal Institute of Engineering and Technology, Faridabad, Haryana, India. Currently, he is pursuing a PhD from the National Institute of Technology, Kurukshetra, Haryana, India. He completed his BTech (Hons.) in mechanical engineering and MTech (Distinction) in manufacturing and automation. His areas of research include materials and their synthesis and characterization techniques, die-less forming, bio-additive manufacturing, CAD/CAM and artificial Intelligence, machine learning and Internet of Things in manufacturing, and multi-objective optimization techniques. He has over 20 publications in international journals of repute including SCOPUS, Web of Science, and SCI indexed database and refereed international conferences. He has more than eight national and international patents in his credit. He has supervised more than 2 MTech scholars and numerous undergraduate projects/theses. He has a total of 12 years of experience in teaching and research. He has co-authored/co-edited the following books:

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- Handbook of Sustainable Materials: Introduction, Modelling, Characterization and Optimization, CRC Press, Taylor and Francis, ISBN: 9781032295874

He has organized a series of faculty development Programs, workshops, and seminars for researchers, UG-level students. He is associated with many research, academic, and professional societies in various capacities.

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1 Smart Manufacturing and Industry 4.0

State-of-the-Art Review

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CONTENTS

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1.1 INTRODUCTION

The term “smart manufacturing,” or SM, was used to describe a new approach to production that is in step with the trends of “industry 4.0”. The potential of I4.0 in data networking and information technology have considerable effect on manufacturing operations [1]. With big data processing, artificial intelligence, and intelligent robots, “smart manufacturing” improves factory output while cutting costs in energy and labour. This allows for the machines and tools that are used in smart manufacturing to be interconnected with one another [2]. Smart manufacturing is a subset of I4.0 that seeks to improve production by applying AI techniques including machine learning, big data analytics, and computer simulations. [3]. It also refers to the adoption of cutting-edge cyber technologies by corporate executives, including enhanced sensing, control, modelling, and platform technologies in I4.0 environment [4].

The manufacturing plans of most influential countries in the global market are focused on the industries of the future. This is a major development in the implementation of intelligent production methods. Germany was the first country to launch the I4.0 initiative for smart manufacturing, which is now recognized across the globe as the generational leap in technology that will revolutionize the manufacturing industry [2]. I4.0 was recognised for the first time in German industries, where it has led to increased productivity with the adoption of SM practices and more effective utilisation of the resources that are available [5,6]. It encouraged the businesses to adopt smart manufacturing practices, IIoT, cloud analytics and big data etc. Notably, it has resulted in high performance and, in comparison to the past, significantly greater positive effects. Role of work, management, and social ecosystem elements in SM need to be considered. [7]. The job profiles are undergoing transformations as a direct result of the opportunities made available by I4.0. Leaders in the corporate and public sectors, as well as academics and practitioners, need to collaborate to learn more about smart manufacturing's potential and its necessary infrastructure. [8,9].

At present, investigations into smart manufacturing are underway, but lacks Industry 4.0 adoption. Also, the present literature is devoid of assessment of the different facets of Industry 4.0 [10]. Several supplementary investigations have delved into the current literature and identified hindrances to the adoption of intelligent manufacturing [10–13]. Zhou et al. [14] examine the main topics of smart factories and SM within the context of Industry 4.0, while also presenting obstacles, prospects, strategic planning, and crucial technologies.

The adoption of I4.0 concept among practitioners is popular as a means of putting smart manufacturing practises into effect. Industry 4.0 is not yet ready to be implemented because there is a lack of technical know-how and terminology [15]. Currently, there is limited knowledge about the possible advantages and disadvantages associated with the introduction of intelligent manufacturing [16,15]. Companies are unable to implement I4.0 because they are unable to comprehend the particulars of the implementation that are relevant to their own organisation [17]. Organizations have not conducted any specific research in their business operations, as such research has not been found [17,15]. As a direct consequence of this, the vast majority of businesses are unable to devise an appropriate strategy for implementing industry 4.0 [18].

For in-depth understanding of the dimensions that influence the success of I4.0 implementation, a Petersen et al. [19] guidelines-based SLR was carried out. The participants in this study will be provided with a tool that will assist them in determining which aspects of their organization are the most important and in formulating a strategy to improve those aspects using the findings of this study.

The entire research paper is broken up into six sections. After the introduction has been finished for section 1, the related work, which is contained in section 2, is presented. The discussion of the methodology can be found in Section 3. Section 4 contains a presentation of the results. In section 5, the validity threats are detailed, and in section 6, the conclusions are discussed.

1.2 RELATED WORK

Numerous research has been performed to identify and evaluate dimensions. All the studies are distinct from one another in terms of the approaches and procedures that were utilized to give the facets of putting the I4.0 concept into practice in manufacturing firms. The contributions that were made by the related work can be found in this section.

In order to give the reader a full picture of what SMSs are and how they work, Qu et al. [20] summarises the background, definition, goals, functional requirements, business needs, and technological requirements of SM. At the same time, it describes where things stand in terms of progress. Based on this, we present a model of autonomous smart manufacturing that is driven by fluctuating demand and key performance measures. The technological differences between traditional production and smart manufacturing were explored by Phuyal et al. [2]. In this study, as well as its current implementation status. Recent developments and their consequences were reviewed for this field.

To ascertain the dimensions, Elibal and Ozceylan [21] conducted a relevant literature study. The authors employed various database search to examine 90 distinct studies. There is a discussion on the categorization of the studies, which includes things like meta-models, combinations of models, comparison models, and so on. To conduct this research, qualitative analysis is performed. In the study, the descriptive evaluation model for the review study was presented, and the limitations of the existing model were discussed. The study has some problems with its validity. Ghobakhloo et al. [7] in their work determined drivers of I4.0 concept. They also described a descriptive evaluation of the 745 studies that were eligible for consideration. The study found that organisational factors, technology factors, and environmental factors are the primary determinants of I4.0. The author discussed both the study's theoretical underpinnings and its potential real-world applications. However, the study does not address whether the model being used is accurate. Hizam-Hanafiah et al. [22] and Kamble et al. [23] analysed various studies and proposed numerous dimensions. The authors identified technology as the most crucial dimension, with 44 percent of the 158 dimensions pertaining to technology. Consequently, technology is deemed the most significant factor. They refer to three critical dimensions, including technology, based on aspects, and process integration. The author put forth strategic guidelines in their proposal. The study does not include the validation component. In their presentation on I4.0 dimensions, Liao et al. [24] used SLR. The author went over the repercussions of putting industry 4.0 into practice as well as the research agenda for the foreseeable future. However, many of the studies suffer from the same types of shortcomings.

Despite the significance and potential opportunities in SM fields with I4.0 adoption, there has been limited research conducted on identifying the dimensions of SM. In this study, the dimensions are identified from selected studies and ranked according to their importance [25]. However, previous studies lack validation aspects as they mostly rely on qualitative analysis without strong evidence to support the SLR. Therefore, the dimensions are identified quantitatively from the selected studies to provide stronger evidence.

1.3 METHODOLOGY

This section presents details about the research techniques that are employed. Following Petersen et al. [19] guidelines for conducting SLR and Aria and Cuccurullo [26] for conducting bibliometric mapping, methodology based on five phases is adopted. In the first phase, the authors define the parameters of the work and formulated research questions. Three research questions are formulated. RQ1 and RQ2 were answered using SLR and RQ3 was answered following the bibliometric analysis. Search methodology is the focus of the next phase. In this step, the author searched for relevant articles in a scientific database by entering a string of search terms that makes use of "AND" and "OR" Operators. In accordance with the approach proposed by Kitchenham and Charters [27], a search string was constructed by combining relevant keywords

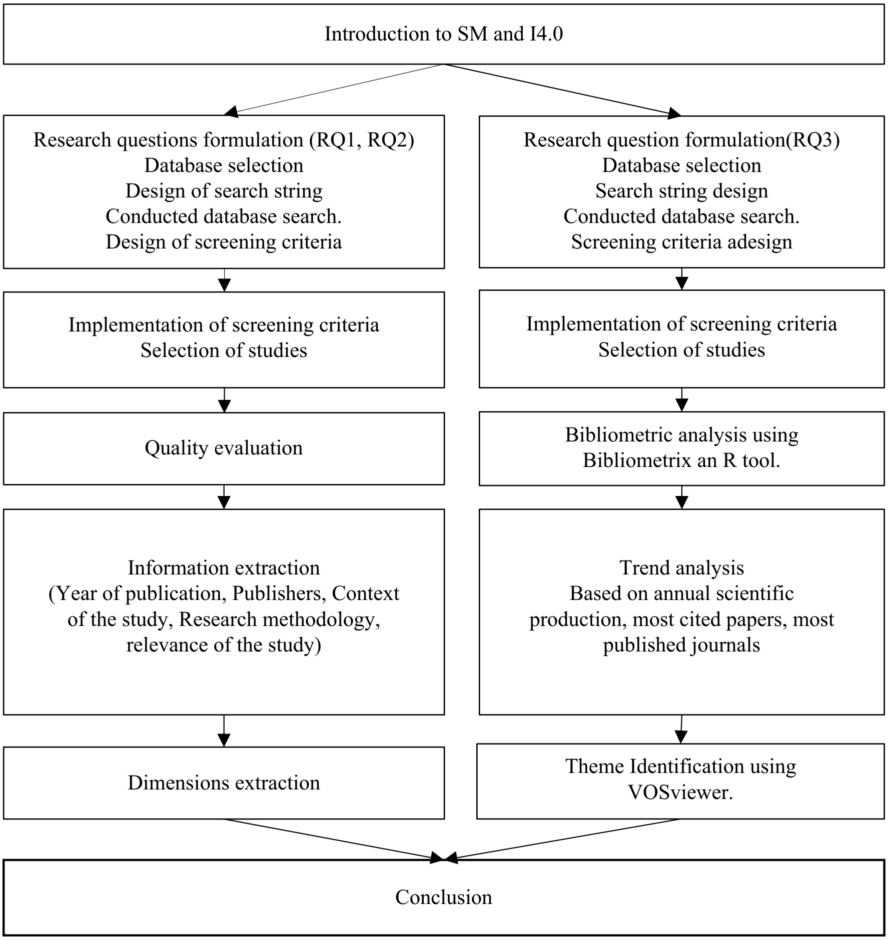

FIGURE 1.1 Methodology flowchart.

using PICO approach. The third phase presents screening of the studies. In the fourth phase, the work is reviewed on the basis of their titles and keywords. The final phase of the study involved mapping research questions. To minimize bias in the study, a quality evaluation was conducted. The results were analyzed and presented in Figure 1.1, which illustrates the research process.

1.3.1 Research Questions

The following research questions are framed to meet the research objectives:

RQ1: What are I4.0 dimensions which help in smart manufacturing?
RQ2: What are those dimensions which are critical for SM systems?
RQ3: What are the future research directions for SM systems?

1.3.2 Search strategy

The work utilized the PICO (Population, intervention, comparison, and outcome) approach recommended by Kitchenham and Charters [27] to guide the search process.

1.3.2.1 Population

It refers to the targeted group. In this study, the population was Smart Manufacturing or Industry 4.0 elements.

1.3.2.2 Intervention

Various maturity models and industry reports served as interventions.

1.3.2.3 Comparison

Empirical studies were conducted to compare the different smart manufacturing techniques and methods.

1.3.2.4 Outcomes

The study's outcomes involved the extensive literature review and empirical analysis of dimensions.

To conduct the study, the author searched for studies in popular databases utilizing search strings tailored to each database. The author utilized the "AND" operator to form the search string. Search string for the databases is as follows:

("smart manufacturing" AND "industry 4.0")

1.3.3 Selection of studies

Our study used screening criteria to select relevant articles. The inclusion year (2007–2022) for articles in English language. We identified seven criteria for selecting articles, labelled as C1 to C7, which are listed in Table 1.1, we provide the criteria that will be used to determine what will and will not be considered for screening.

1.3.4 Data extraction

The study has gathered information regarding smart manufacturing. Additionally, a data attributes sheet has been generated that outlines the research questions (See Table 1.2).

1.3.5 Quality evaluation

According to the standards in Table 1.3, a quality evaluation has been performed. The purpose of this step was to ensure that only relevant studies were considered and to strengthen the validity of our findings. For a comprehensive breakdown of the quality evaluation scores, please refer to Table A1 in appendix section.

TABLE 1.1
Criteria for Screening

Criteria Id	Criteria Type	Explanation
C1	Inclusion	Publication year: 2007–2022
C2	Inclusion	English language articles
C3	Exclusion	Books, book chapters, dissertations, and theses
C4	Exclusion	Articles containing less than six pages
C5	Inclusion	Articles including the terms “SM,” “I4.0,” and “digital transformation”.
C6	Inclusion	Articles that address SM and I4.0.

TABLE 1.2
The Data Attributes in the Present Study

Class	Elements	Address Research Question
Intuitive information	Publication year, publisher, author, title and abstract	1
Methodology	Study design, case study, survey, evaluation study	2
Setting	Work motivation, validity threats, subjective research	2
Results and conclusion	Work limitations, address challenges, future work discussion	1, 2

TABLE 1.3
Quality Evaluation Parameters (QEP)

QEP ID	Description
QEP1	Does the article state its research aims clearly?
QEP2	Does the study explore dimensions related to its research aims?
QEP3	Does the article provide a literature review and outline the main contributions?
QEP4	Does the work describe the design of research methodology?
QEP5	Does the study present research findings?
QEP6	Are the research objectives and conclusions of the work explained in a clear manner?
QEP7	Does the article discuss future research or areas for further investigation?

1.4 RESULTS AND DISCUSSION

1.4.1 Discussion on RQ1 and RQ2

In accordance with Petersen et al. [19], the results of SLR are discussed. A pilot study was conducted using PICO criteria [28] to develop the search string. Applying the search criteria to the databases identified 3001 studies, which were screened based on selection criteria and publication date from 2007 to 2022. This resulted in 115 studies, with 40 duplicates removed, leaving 75 studies for quality assessment. Based on quality scores less than 3, approximately 13.37% of studies were removed, and 65 final articles were selected for the study. The search results are shown in Table 1.4. The number of academic studies showed a constant trend from 2007 to 2015, with only 1 or 2 studies, but the trend increased continuously from 2016–2022. The distribution of primary research according to year is presented in Figure 1.2.

The author aimed to respond to RQ1 by identifying dimensions. Additionally, the author calculated the frequency/percentage of each dimension. The authors identified 8 dimensions. To address RQ2, the author selected five dimensions that had a percentage equal to or greater than 25%. Table 1.5 provides the order and variables of the identified dimensions.

1.4.1.1 Technology (E_8)

The study found that technology is the most significant dimension in SMEs' digital readiness, with 92.31% of the selected studies focusing on various technological areas. Cyber-physical systems, as noted by Rahamaddula et al. [29] and Swarnima et al. [30], are particularly critical for integrating digital and physical entities. Saad et al. [31] outlines the importance of technology in smart manufacturing in industry 4.0 environment has further highlighted the growing significance of AI, ML, and cloud computing [32–34].

1.4.1.2 Organizational strategy (E_1)

The study identifies the second most significant dimension as strategy with a frequency of 30. 46.15% studies considered organization strategy as a dimension for smart manufacturing. Strategy involves planning for products and services that align with smart manufacturing requirements. Additionally, the strategy includes the funding strategy, which refers to the financial investment made for implementing smart manufacturing practices.

1.4.1.3 People/culture/employees (E_3)

The current research reveals that people/culture is identified as crucial dimensions. It is ranked at 5 with frequency 17 and 26.15%. This dimension relates to the employee attitude towards use of digital means for work [35,36,29]. As a final recommendation, it is essential to foster a learning culture to achieve smart manufacturing culture [37]. People/culture/employees are crucial to the success of SM. A skilled workforce and a culture of collaboration and continuous improvement are essential for implementing and optimizing advanced technologies.

TABLE 1.4
Search Results

Name of Database Library	Search Count	Articles Left after Applying Screening Criteria						Articles Left after Removing Duplicates	Articles Remaining after Quality Evaluation
		C1	C2	C3	C4	C5	C6		
ScienceDirect	2430	2428	2421	1315	785	286	50	75	65
ACM	115	108	133	109	93	50	22		
Wiley	209	209	200	143	123	56	25		
JSTOR	22	22	20	16	10	8	3		
DOAJ	225	225	172	150	96	76	15		
Total	3001	2992	2946	1733	1107	351	115	75	65

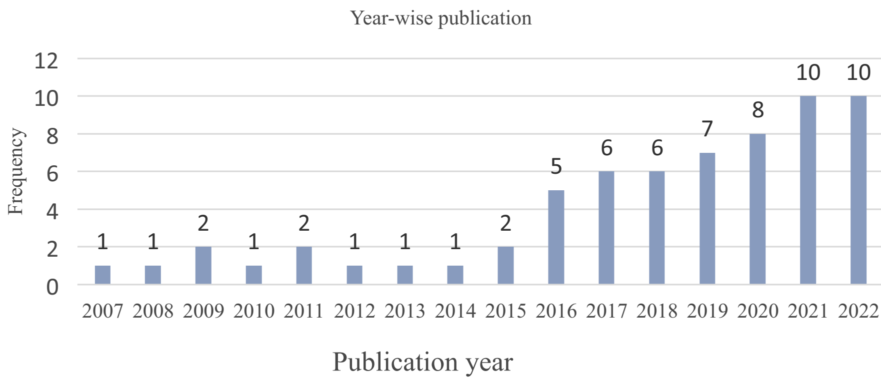

FIGURE 1.2 Year-wise studies.

1.4.1.4 Processes (E4)

smart manufacturing processes are crucial to the success of modern manufacturing operations. By optimizing processes, manufacturers can increase efficiency, reduce waste, improve product quality, and be more responsive to customer needs, ultimately leading to greater competitiveness in the marketplace. Findings reveals that, processes with frequency 27 and 41.54 % were ranked third. This dimension encompasses various types of processes such as business, communication, and management processes.

1.4.1.5 Products (E_6)

Product as a dimension (Frequency 21, percentage 32.31) ranked at four. One of the main goal of SM is to produce high-quality products that meet or exceed customer expectations while minimizing waste and reducing costs. It requires in-depth knowledge of the product and its manufacturing process [34]. Digital features in products enhance customer interest and promote association with the industry 4.0 ecosystem [38–41].

1.4.1.6 Customers (E_5)

According to the study, the sixth-ranked dimension is customers (Frequency 12 and percentage 18.46). Customers are important in smart manufacturing because they have high expectations for the products they purchase. They want products that are high-quality, reliable, and meet their specific needs. By understanding customer preferences and behaviours, manufacturers can tailor their products to meet those needs more effectively. This can lead to increased customer satisfaction and loyalty, which is essential for the long-term success of any business [5,29].

1.4.1.7 Innovation (E_2)

According to the information provided in Table 1.5, innovation (Frequency 10, percentage 16.67) is ranked seventh among the critical dimensions for industry 4.0.

TABLE 1.5
Identified Variables

S. no.	Dimensions	Definition	References	Frequency	Percentage	Ranking
E_1	Organisational Strategy	Organisational Strategy refers to the approach and plan of action adopted by an organization to align its resources, goals, and capabilities with the opportunities and challenges posed by the new technologies and digitalization. It involves the development of a clear roadmap for Industry 4.0 adoption, infrastructure, organizational structure, workforce planning, and continuous improvement strategies. Organisational strategy is critical for SMEs in their implementation of smart manufacturing practices ensuring its long-term sustainability and competitiveness.	[3,17,42–51,30,52–61,35–41]	30	46.15	2
E_2	Innovation	Innovation in this context includes the exploration and implementation of new business models, supply chain strategies, and value creation opportunities to stay competitive in the rapidly evolving digital landscape.	[33,39,40,43,44,47,51,59,62, 63]	10	16.67	7
E_3	People/culture/ Employees	People/culture/employees refer to the human aspect of the organization, including its employees' skills, knowledge, behaviour, and attitudes towards digital transformation. It involves the organization's culture, values, leadership, and change management strategies necessary for successful adoption of smart manufacturing practices. It also includes the development of a skilled workforce capable of operating and maintaining advanced digital technologies.	[17,29,58,60,62,64–67,33, 36–39,44–46]	17	26.15	5

(*Continued*)

TABLE 1.5 (Continued)
Identified Variables

S. no.	Dimensions	Definition	References	Frequency	Percentage	Ranking
E_4	Processes	Processes refer to the methods and procedures used in making products. It includes adoption of technology with process automation, industrial robots. Processes in I4.0 involve the integration of various systems across the entire value chain, including design, production, supply chain, logistics, and customer service. Smart processes are designed to be flexible, adaptable, and responsive to changes in customer demand, market trends, and technological advancements.	[3,29,50,55,60–63,65, 66,68,69,33,70–75,35–38,43, 38,43,45,46]	27	41.54	3
E_5	Customers	This dimension includes understanding and meeting customer expectations, providing customer-tailored products, and using data analytics to improve customer experience. Customer retention is a key focus, and companies strive to create a customer-centric environment to improve their competitiveness in the market.	[29,36,64,76,38,39,42,44, 55,57,60,62]	12	18.46	6
E_6	Products	Products refers to the physical goods or digital services produced by a company or organization using advanced technologies and processes. These products may be customized or personalized for individual customers and may incorporate digital features and connectivity to enhance their functionality and value.	[3,35,62,64,65,69–73,75,77, 36,78,38,42,43,46,57,59,60]	21	32.31	4

E_7	Services	Services refers to the digital features and capabilities that are integrated with the products offered by an organization. This includes data-driven services, remote monitoring, product configuration, product simulation, and condition monitoring, among others. By leveraging digital technologies and integrating them with their products, organizations can improve their competitiveness and customer satisfaction.	[35,36,44,50,59,60,64,71,79]	9	13.85	8
E_8	Technology	It involves the integration of physical and cyber systems, resulting in smart and efficient manufacturing processes. Technology is a critical dimension in Industry 4.0 as it enables companies to improve their operations, increase productivity, reduce costs, and develop new products and services.	[3,7,38–40,42–46,50,51,17, 52–55,57–60,62,63,29, 64–73,30,74–83,31,84–90, 33,35–37,91,92]	60	92.31	1

Innovation allows manufacturers to improve their processes and operations, resulting in reduced costs and improved quality. For example, the implementation of predictive maintenance systems can reduce downtime and prevent costly equipment failures. Similarly, the use of robotics and automation can increase production efficiency and reduce labour costs.

Innovation can also enable manufacturers to create new products and services, opening new markets and revenue streams. For example, smart products equipped with sensors can provide valuable data used to improve customer satisfaction.

1.4.1.8 Services (E_7)

According to the findings presented in Table 1.5, the dimension of services ranks at the eighth position (frequency 9, percentage 13.85. In I4.0, services refer to the digital features offered by an organization that attract end-users to adapt to the industry 4.0 environment. Such services may include product configuration, development, and simulation, as well as remote and condition monitoring, and other data-driven services that are integrated with digital technologies.

Sections 4.1.1 through 4.1.8 presents discussion on variables. Based on the analysis, it is apparent that Technology (E8), Organizational strategy (E1), Processes (E4), Products (E6), and People/culture/employees (E3) are the most crucial dimensions for SMEs. Dimensions reporting a frequency of more than 25% considered critical. The selection of these critical dimensions is subjective, and further input from experts in the field may be necessary to support the findings.

1.4.2 Discussion on RQ3

For the identification of future research theme, the authors have conducted bibliometric analysis. The work is done on Bibliometrix and Vosviewer. The authors selected the WoS database. Authors designed the search string such that it covers the objective of the chapter. The search string is as follows: ("smart manufacturing" AND "industry 4.0"). the authors conducted the search from the web of science database using the string followed by screening of the articles (Table 1.6).

186 articles are selected for further analysis. The authors have gone through the most relevant sources. The analysis shows that the IJPR journal receives a total of 598 citations on the topic followed by Journal of manufacturing systems with 386 citations. Figure 1.3 shows the most cited sources form the smart manufacturing and industry 4.0.

The authors now conducted the keyword cooccurrence analysis using VOSviewer. Which result in making the five clusters. Figure 1.4 shows the keyword cooccurrence analysis and clusters. These clusters are identified by the colors. Each cluster contain several elements. The details of the clusters are given in Table 1.7.

TABLE 1.6
Screening Results

Description	Type	Article Count
Search using keywords (“smart manufacturing” AND “industry 4.0”)	Inclusion	609
Review article	Exclusion	504
Editorial material	Exclusion	495
Proceeding paper	Exclusion	492
Web of science categories such as engineering industrial, operation management, Engineering manufacturing, computer science and AI, automation control systems, engineering mechanical	Inclusion	233
Citation topics meso such as design and manufacturing, supply chain and logistics, management, AI and ML, manufacturing, human computer interaction, knowledge engineering and representation	Inclusion	186
Analysis of title, abstract, keywords	Inclusion	184

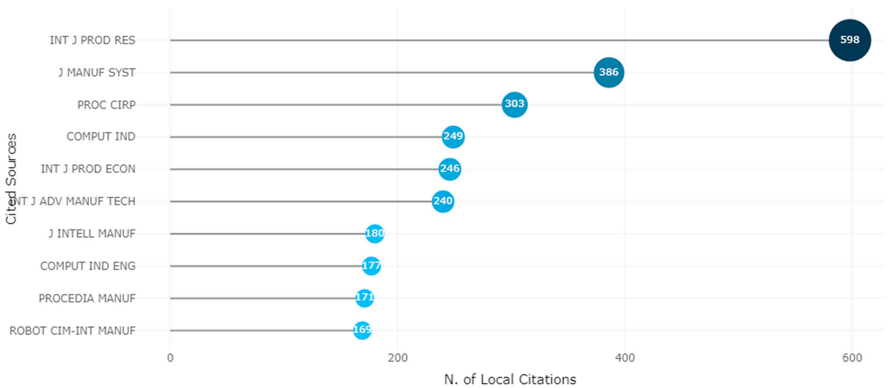

FIGURE 1.3 Most cited sources.

1.4.2.1 Theme based on blue cluster.

“Enhancing Smart Manufacturing through CPS and Industrial Internet: Investigating Decision-Making in Smart Factories.”

The theme directs researchers and academicians to exploring the challenges and barriers to the implementation of SM systems in I4.0 environment and developing strategies to overcome them. The research will investigate how CPS

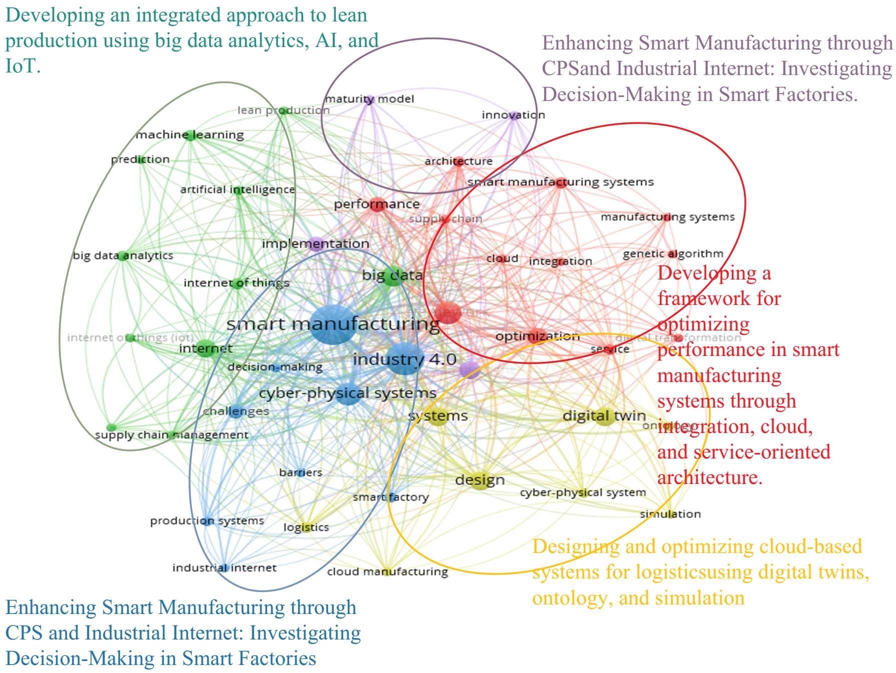

FIGURE 1.4 keyword cooccurrence network analysis with research themes.

and IIoT can be integrated to create a smart factory environment. The decision-making processes involved in the implementation of such systems will also be studied to ensure effective implementation. Finally, the proposed strategies will be evaluated in terms of their effectiveness in addressing the identified challenges and barriers and their ability to facilitate the implementation of SM systems in I4.0 environment.

1.4.2.2 Theme based on yellow cluster.

> ***"Designing and optimizing cloud-based systems for logistics using digital twins, ontology, and simulation."***

This covers areas on utilizing cloud manufacturing, digital twins, and simulation technologies to design and optimize manufacturing and logistics systems. The design aspect of this theme emphasizes the importance of considering both product and process design in the development of such systems. Ontology can be used to standardize data and communication protocols, while logistics can help ensure efficient material flow and inventory management. Finally, the use of digital twins allows for virtual testing and optimization of the proposed systems before implementation, reducing risks and costs.

TABLE 1.7
Cluster Items with Proposed Themes

Cluster colour	Items (Occurrence)	Sub-Items (Occurrence)	Proposed Theme	References
Blue	Smart manufacturing (116) Industry 4.0 (78)	Barriers (5), challenges (15), cyber-physical systems (36), decision-making (7), industrial internet (5), industry 4.0 (78), production systems (7), smart factory (8), smart manufacturing (116)	Enhancing Smart Manufacturing through CPS and Industrial Internet: Investigating Decision-Making in Smart Factories.	[93–99]
Yellow	Systems (26) Digital twin (25) Design (25)	cloud manufacturing (5), cloud manufacturing (7), design (25), digital twin (25), logistics (8), ontology (7), simulation (5), systems (26)	Designing and optimizing cloud-based systems for logistics using digital twins, ontology, and simulation	[93,94]
Red	Framework (37), Optimization (20)	Architecture (8), cloud (5), digital transformation (5), framework (37), genetic algorithm (5), integration (5), manufacturing systems (6), optimization (20), performance (17), service (8), smart manufacturing systems (9), supply chain (6)	Developing a framework for optimizing performance in smart manufacturing systems through integration, cloud, and service-oriented architecture.	[95,98,99,100]
Green	Big data analytics (40) Internet (22)	AI (7), big data analytics (40), cloud computing (5), internet (22), IoT (14), lean production (5), machine learning (10), prediction (5), supply chain management (6)	Developing an integrated approach to lean production using big data analytics, AI, and IoT.	[93,97,98,101]
Purple	Management (23) Implementation (17)	Implementation (17), innovation (7), management (23), maturity model (7)	Developing a maturity model for effective innovation management implementation	[93,95,96]

1.4.2.3 Theme based on red cluster.

Developing a framework for optimizing performance in smart manufacturing systems through integration, cloud, and service-oriented architecture.

This theme focuses on developing framework that incorporates elements of cloud computing, service-oriented architecture, and integration to optimize performance in smart manufacturing systems. The framework will be developed through digital transformation of existing manufacturing systems and supply chain networks. Optimization techniques such as genetic algorithms will be used to fine-tune the system performance. The use of SM systems can help ensure effective data collection, decision-making. Finally, the framework will be evaluated to improve the performance of SM systems in real-world settings.

1.4.2.4 Theme based on green cluster.

"Developing an integrated approach to lean production using big data analytics, AI, and IoT."

The theme focuses on utilizing big data analytics to improve SCM by developing a framework that incorporates IoT, ML, and AI. The framework will be deployed on cloud computing platforms and will leverage lean production principles to reduce waste and improve efficiency. The internet will play a key role in facilitating data exchange and communication between different supply chain partners. The use of ML will enable prediction of supply chain events and help in making data-driven decisions.

1.4.2.5 Theme based on purple cluster.

"Developing a maturity model for effective innovation management implementation".

It focuses on developing a maturity model for effective innovation management implementation. The research points towards identification of factors that help in innovation management implementation. The maturity model can help organizations assess their current innovation management capabilities and identify areas for improvement. The research can use case studies to evaluate the effectiveness of model in different organizational contexts. The findings of the research can help organizations improve their innovation management capabilities and drive growth and competitiveness.

1.4.2.6 Co-citation network analysis

The authors have conducted the co-citation network analysis for deeper understanding of the emerging themes. Analysis was done using the tool VOSviewer. The result of co-citation network reveals that there are four clusters with minimum cluster size 17 and minimum link strength 2. Figure 1.5 shows the co-citation

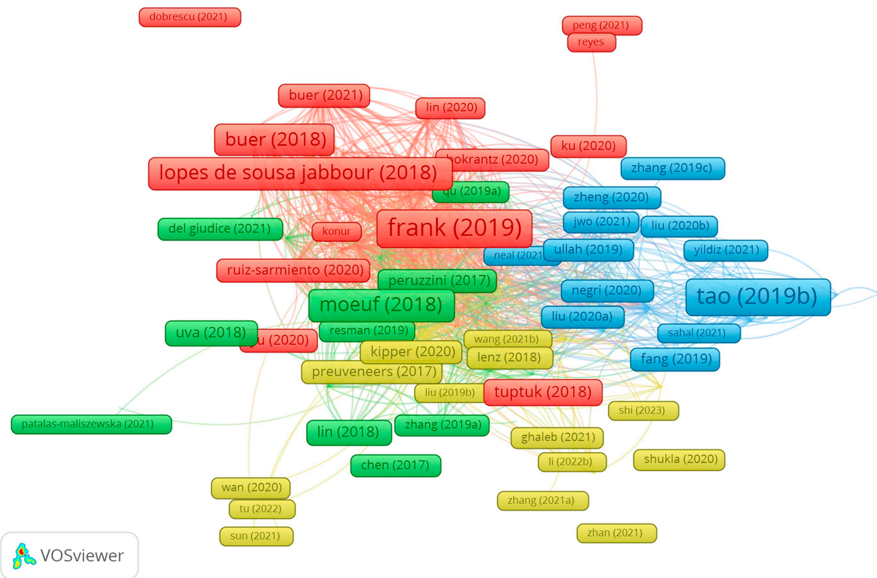

FIGURE 1.5 Co-citation network analysis of articles (VOS viewer).

network analysis of the selected articles. Table 1.8 presents the co-citation network details with top terms and themes.

The themes discussed can be used for research in smart manufacturing by providing a framework for investigating and improving various aspects of manufacturing operations, including maintenance, supply chain management, logistics, quality control, and performance optimization. For example, researchers can explore how data-driven approaches, such as condition-based monitoring and predictive maintenance, can be leveraged to improve equipment reliability and reduce downtime. Collaborative networks and cyber-physical systems can be studied to enable effective communication and coordination between different parts of the manufacturing process, from suppliers to customers. Augmented reality and machine vision can be investigated to enhance human-centered manufacturing, while blockchain and security monitoring can be explored to ensure data integrity and cyber resilience. Optimization techniques, such as simulation modelling and parameter identification, can be applied to improve manufacturing efficiency and quality.

Overall, the discussed themes provide a comprehensive framework for investigating various research questions related to smart manufacturing and offer opportunities for improving manufacturing processes through the integration of advanced technologies and data-driven approaches.

1.5 VALIDITY THREATS

Despite the use of SLR guidelines there are still potential validity issues with the findings. To further minimize bias, we followed the selection criteria guidelines and invited a guest researcher to validate the study selections, resulting in a 70% agreement

TABLE 1.8
Co-Citation Network Details with Themes

Cluster (Colour)	Name of Themes	Items Count	Year (Mean)	Top Terms
1 (Red)	Optimizing Industrial Maintenance and Supply Chain through Collaborative Networks and Big Data Ecosystems	42	2021	Collaborative network, success factors, industrial maintenance, operational performance, bigdata ecosystems, predictive maintenance, smart manufacturing, supply chain, inventory management, security, collaborative robots, toe framework, cps, lean supply chain, big data analytics, cyber-security challenges, sustainable I4.0, manufacturing scm, hybrid manufacturing
2 (Green)	Enabling Agile and Customizable Manufacturing through Data-Driven Approaches and Augmented Reality	31	2019	Data-driven scheduling, changeability, reconfigurability, augmented reality, cloud manufacturing, product-service system, feasibility evaluation, optimization, self-tuning model, operationalization framework, strategic response, cyber-physical production network, industrial management, management approach, human-cantered additive manufacturing, enterprise information systems, SM systems requirements, augmented reality-based SM, machine vision, mass personalization.
3 (Blue)	Enhancing Manufacturing Performance and Security through Digital Twins and Autonomous Collaboration	29	2021	Optimization, onto-based modelling, digital twin, CPS, autonomous collaboration, reinforcement learning, human-in-the-loop SM, web-based digital twin, security monitoring, quality, mes integration, cognitive twin, blockchain, data formats, human decision models, simulation modelling, product management, iot enabled, simulation-based approach, edge computing.
4 (Yellow)	Maximizing Efficiency and Quality in Industry 4.0 Ecosystems through Condition-Based Monitoring and Data-Driven Approaches	21	2020	Condition-based monitoring, synchroperation, bottleneck detection model, data-driven models, data analytics, SM systems, cyber-physical factories, logistics management, quality improvement, I4.0 ecosystem, parameter identification, machine learning, training, anomaly detection model, dynamic environment.

on the selections. However, there is still the possibility of publication bias, where researchers may only present positive results from their research. To address this, we utilized multiple search libraries. Finally, there is a possibility of data extraction bias, but we minimized it by using a data extraction template to record unbiased data.

Also, there may be the possibility of biasness while conducting bibliometric analysis such as biasness in database selection, incompleteness of data, citation practices, self-citations, inaccurate citation data, changing publication practices etc. However, to avoid such threats, the authors have conducted the word co-occurrence network analysis and co-citation network analysis for exploring future research directions.

1.6 CONCLUSION

Smart manufacturing has emerged as a transformative approach to manufacturing that integrates cutting-edge technologies and innovative processes to enable more efficient, flexible, and sustainable production. The success of smart manufacturing depends on several dimensions that are critical for achieving operational excellence and competitive advantage. To this end, the author conducted review of studies published from 2007 to 2022, eight dimensions that aid manufacturing firms in opting smart manufacturing practices. RQ1 was addressed by extracting data from 65 studies to identify 8 key dimensions, namely technology, organizational strategy, people/culture/employees, processes, products, customers, innovation, and services. To address RQ2, dimensions (Count percentage > 25%), which included technology, organizational strategy, products, processes, and people/culture/employees. The RQ3 was addressed by conducting a bibliometric analysis resulting in five potential research directions (keyword co-occurrence network analysis) and another four themes (using co-citation network analysis). This finding underscores the high demand for research on smart manufacturing. These findings can inform future smart manufacturing research. Further work on these themes can add value to research domain and ultimately lead to achieve socio-economic goals.

REFERENCES

[1] J. Davis *et al.*, “Smart Manufacturing,” *Annu. Rev. Chem. Biomol. Eng.*, vol. 6, no. April, pp. 141–160, 2015, doi: 10.1146/annurev-chembioeng-061114-123255.

[2] S. Phuyal, D. Bista, and R. Bista, “Challenges, Opportunities and Future Directions of Smart Manufacturing: A State of Art Review,” *Sustain. Futur.*, vol. 2, no. March, p. 100023, 2020, doi: 10.1016/j.sftr.2020.100023.

[3] F. Bachinger, G. Kronberger, and M. Affenzeller, “Continuous improvement and adaptation of predictive models in smart manufacturing and model management,” *IET Collab. Intell. Manuf.*, vol. 3, no. 1, pp. 48–63, 2021, doi: 10.1049/cim2.12009.

[4] M. Shahin, F. F. Chen, H. Bouzary, and K. Krishnaiyer, “Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises,” *Int. J. Adv. Manuf. Technol.*, vol. 107, no. 5–6, pp. 2927–2936, 2020, doi: 10.1007/s00170-020-05124-0.

[5] J. M. Müller, O. Buliga, and K. I. Voigt, “The role of absorptive capacity and innovation strategy in the design of industry 4.0 business Models - A comparison between SMEs and large enterprises,” *Eur. Manag. J.*, vol. 39, no. 3, pp. 333–343, 2021, doi: 10.1016/j.emj.2020.01.002.

[6] A. Felsberger, F. Hasan Qaiser, A. Chaudhary, and G. Reiner, "Felsberger et al. The impact of Industry 4.0 on the reconciliation of dynamic capabilities evidence from the European manufacturing indu-annotated.pdf," *Prod. Plan. Control*, vol. 33, no. 2–3, pp. 277–300, 2022, doi: 10.1080/09537287.2020.1810765.
[7] M. Ghobakhloo and M. Iranmanesh, "Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs," *J. Manuf. Technol. Manag.*, vol. 32, no. 8, pp. 1533–1556, 2021, doi: 10.1108/JMTM-11-2020-0455.
[8] M. Ghobakhloo, "Industry 4.0, digitization, and opportunities for sustainability," *J. Clean. Prod.*, vol. 252, p. 119869, 2020, doi: 10.1016/j.jclepro.2019.119869.
[9] S. V. Shet and V. Pereira, "Proposed managerial competencies for Industry 4.0 – Implications for social sustainability," *Technol. Forecast. Soc. Change*, vol. 173, no. March, p. 121080, 2021, doi: 10.1016/j.techfore.2021.121080.
[10] B. Bajic, A. Rikalovic, N. Suzic, and V. Piuri, "Industry 4.0 Implementation Challenges and Opportunities: A Managerial Perspective," *IEEE Syst. J.*, vol. 15, no. 1, pp. 546–559, 2021, doi: 10.1109/JSYST.2020.3023041.
[11] A. Raj, G. Dwivedi, A. Sharma, A. B. Lopes de Sousa Jabbour, and S. Rajak, "Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective," *Int. J. Prod. Econ.*, vol. 224, no. August 2019, p. 107546, 2020, doi: 10.1016/j.ijpe.2019.107546.
[12] G. Orzes, E. Rauch, S. Bednar, and R. Poklemba, "Industry 4.0 Implementation Barriers in Small and Medium Sized Enterprises: A Focus Group Study," *IEEE Int. Conf. Ind. Eng. Eng. Manag.*, vol. 2019-Decem, pp. 1348–1352, 2019, doi: 10.1109/IEEM.2018.8607477.
[13] A. G. Frank, L. S. Dalenogare, and N. F. Ayala, "Industry 4.0 technologies: Implementation patterns in manufacturing companies," *Int. J. Prod. Econ.*, vol. 210, no. September 2018, pp. 15–26, 2019, doi: 10.1016/j.ijpe.2019.01.004.
[14] K. Zhou, T. Liu, and L. Zhou, "Industry 4.0: Towards future industrial opportunities and challenges," *2015 12th Int. Conf. Fuzzy Syst. Knowl. Discov. FSKD 2015*, pp. 2147–2152, 2016, doi: 10.1109/FSKD.2015.7382284.
[15] A. Issa, B. Hatiboglu, A. Bildstein, and T. Bauernhansl, "Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment," *Procedia CIRP*, vol. 72, pp. 973–978, 2018, doi: 10.1016/j.procir.2018.03.151.
[16] K. Y. Akdil, A. Ustundag, and E. Cevikcan, *Maturity and Readiness Model for Industry 4.0 Strategy*. 2018.
[17] L. Bibby and B. Dehe, "Defining and assessing industry 4.0 maturity levels–case of the defence sector," *Prod. Plan. Control*, vol. 29, no. 12, pp. 1030–1043, 2018, doi: 10.1080/09537287.2018.1503355.
[18] K. Lichtblau *et al.*, "IMPULS-Industrie 4.0-Readiness," 2015.
[19] K. Petersen, S. Vakkalanka, and L. Kuzniarz, "Guidelines for conducting systematic mapping studies in software engineering: An update," *Inf. Softw. Technol.*, vol. 64, pp. 1–18, 2015, doi: 10.1016/j.infsof.2015.03.007.
[20] Y. J. Qu, X. G. Ming, Z. W. Liu, X. Y. Zhang, and Z. T. Hou, "Smart manufacturing systems: state of the art and future trends," *Int. J. Adv. Manuf. Technol.*, vol. 103, no. 9–12, pp. 3751–3768, 2019, doi: 10.1007/s00170-019-03754-7.
[21] K. Elibal and E. Özceylan, "A systematic literature review for industry 4.0 maturity modeling: state-of-the-art and future challenges," *Kybernetes*, vol. 50, no. 11, pp. 2957–2994, 2021, doi: 10.1108/K-07-2020-0472.
[22] M. Hizam-hanafiah, M. A. Soomro, and N. L. Abdullah, "Industry 4.0 Readiness Models.Pdf," 2020.

[23] S. S. Kamble, A. Gunasekaran, and S. A. Gawankar, "Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives," *Process Saf. Environ. Prot.*, vol. 117, pp. 408–425, 2018, doi: 10.1016/j.psep.2018.05.009.

[24] Y. Liao, F. Deschamps, E. de F. R. Loures, and L. F. P. Ramos, "Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal," *Int. J. Prod. Res.*, vol. 55, no. 12, pp. 3609–3629, 2017, doi: 10.1080/00207543.2017.1308576.

[25] A. A. Khan, J. W. Keung, Fazal-E-Amin, and M. Abdullah-Al-Wadud, "Spiimm: Toward a model for software process improvement implementation and management in global software development," *IEEE Access*, vol. 5, no. c, pp. 13720–13741, 2017, doi: 10.1109/ACCESS.2017.2728603.

[26] Aria, M. and Cuccurullo, C. "Bibliometrix: An R-tool for comprehensive science mapping analysis," *Journal of Informetrics*, vol. 11, no. 4, pp. 959–975, 2017.

[27] B. Kitchenham and S. M. Charters, "Guidelines for performing Systematic Literature Reviews in Software Engineering Guidelines for performing Systematic Literature Reviews in Software Engineering EBSE Technical Report EBSE-2007-01 Software Engineering Group School of Computer Science and Ma," no. January, 2007.

[28] M. B. Eriksen and T. F. Frandsen, "The impact of patient, intervention, comparison, outcome (PICO) as a search strategy tool on literature search quality: a systematic review," vol. 106, no. October, pp. 420–431, 2018.

[29] S. R. Bin Rahamaddulla, Z. Leman, B. T. H. T. Bin Baharudin, and S. A. Ahmad, "Conceptualizing smart manufacturing readiness-maturity model for small and medium enterprise (Sme) in malaysia," *Sustain.*, vol. 13, no. 17, pp. 1–18, 2021, doi: 10.3390/su13179793.

[30] C. Swarnima, P. Mehra, and A. Dasot, "India's Readiness for Industry 4.0 – A Focus on Automotive Sector," *Grant Thornt. Indian*, p. 46, 2017, [Online]. Available: http://www.grantthornton.in/insights/articles/indias-readiness-for-industry-4.0--a-focus-on-automotive-sector/.

[31] S. M. Saad, R. Bahadori, and H. Jafarnejad, "The smart SME technology readiness assessment methodology in the context of industry 4.0," *J. Manuf. Technol. Manag.*, vol. 32, no. 5, pp. 1037–1065, 2021, doi: 10.1108/JMTM-07-2020-0267.

[32] M. M. Queiroz, S. C. F. Pereira, R. Telles, and M. C. Machado, "Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities," *Benchmarking*, 2019, doi: 10.1108/BIJ-12-2018-0435.

[33] E. Rauch, P. Dallasega, and M. Unterhofer, "Requirements and Barriers for Introducing Smart Manufacturing in Small and Medium-Sized Enterprises," *IEEE Eng. Manag. Rev.*, vol. 47, no. 3, pp. 87–94, 2019, doi: 10.1109/EMR.2019.2931564.

[34] Z. Suleiman, S. Shaikholla, D. Dikhanbayeva, E. Shehab, and A. Turkyilmaz, "Industry 4.0- Clustering of concepts and characteristics," *cogent Eng.*, vol. 9, no. 1, p. 2034264, 2022.

[35] F. Tao, Q. Qi, L. Wang, and A. Y. C. Nee, "Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison," *Engineering*, vol. 5, no. 4, pp. 653–661, 2019, doi: 10.1016/j.eng.2019.01.014.

[36] K. Traganos, P. Grefen, I. Vanderfeesten, J. Erasmus, G. Boultadakis, and P. Bouklis, "The HORSE framework: A reference architecture for cyber-physical systems in hybrid smart manufacturing," *J. Manuf. Syst.*, vol. 61, no. October, pp. 461–494, 2021, doi: 10.1016/j.jmsy.2021.09.003.

[37] E. Pessl, S. R. Sorko, and B. Mayer, "Roadmap industry 4.0 - Implementation guideline for enterprises," *Int. J. Sci. Technol. Soc.*, vol. 5, no. 6, pp. 193–202, 2017, doi: 10.11648/j.ijsts.20170506.14.

[38] D. Guo *et al.*, "Synchroperation in industry 4.0 manufacturing," *Int. J. Prod. Econ.*, vol. 238, no. March, p. 108171, 2021, doi: 10.1016/j.ijpe.2021.108171.
[39] S. Krishnan, S. Gupta, M. Kaliyan, V. Kumar, and J. A. Garza-Reyes, "Assessing the key enablers for Industry 4.0 adoption using MICMAC analysis: a case study," *Int. J. Product. Perform. Manag.*, vol. 70, no. 5, pp. 1049–1071, 2021, doi: 10.1108/IJPPM-02-2020-0053.
[40] D. Horvat, T. Stahlecker, A. Zenker, C. Lerch, and M. Mladineo, "A conceptual approach to analysing manufacturing companies' profiles concerning Industry 4.0 in emerging economies," *Procedia Manuf.*, vol. 17, pp. 419–426, 2018, doi: 10.1016/j.promfg.2018.10.065.
[41] J. C. Serrano-Ruiz, J. Mula, and R. Poler, "Development of a multidimensional conceptual model for job shop smart manufacturing scheduling from the Industry 4.0 perspective," *J. Manuf. Syst.*, vol. 63, no. January, pp. 185–202, 2022, doi: 10.1016/j.jmsy.2022.03.011.
[42] G. Liu *et al.*, "Two-stage Competitive Particle Swarm Optimization Based Timing-driven X-routing for IC Design under Smart Manufacturing," *ACM Trans. Manag. Inf. Syst.*, 2022, doi: 10.1145/3531328.
[43] D. Li, "Perspective for smart factory in petrochemical industry," *Comput. Chem. Eng.*, vol. 91, pp. 136–148, 2016, doi: 10.1016/j.compchemeng.2016.03.006.
[44] A. Iyer, "Moving from Industry 2.0 to Industry 4.0: A case study from India on leapfrogging in smart manufacturing," *Procedia Manuf.*, vol. 21, pp. 663–670, 2018, doi: 10.1016/j.promfg.2018.02.169.
[45] F. Pirola, C. Cimini, and R. Pinto, "Digital readiness assessment of Italian SMEs: a case-study research," *J. Manuf. Technol. Manag.*, vol. 31, no. 5, pp. 1045–1083, 2019, doi: 10.1108/JMTM-09-2018-0305.
[46] S. Parhi, K. Joshi, T. Wuest, and M. Akarte, "Factors affecting Industry 4.0 adoption – A hybrid SEM-ANN approach," *Comput. Ind. Eng.*, vol. 168, no. March 2021, p. 108062, 2022, doi: 10.1016/j.cie.2022.108062.
[47] F. Nwaiwu, M. Duduci, F. Chromjakova, and C. A. F. Otekhile, "Industry 4.0 concepts within the czech sme manufacturing sector: An empirical assessment of critical success factors," *Bus. Theory Pract.*, vol. 21, no. 1, pp. 58–70, 2020, doi: 10.3846/btp.2020.10712.
[48] H. Wang and B. Lin, "Pipelined van Emde Boas tree: Algorithms, analysis, and applications," *Proc. – IEEE INFOCOM*, pp. 2471–2475, 2007, doi: 10.1109/INFCOM.2007.303.
[49] M. Lassnig, J. M. Müller, K. Klieber, A. Zeisler, and M. Schirl, "A digital readiness check for the evaluation of supply chain aspects and company size for Industry 4.0," *J. Manuf. Technol. Manag.*, vol. 33, no. 9, pp. 1–18, 2018, doi: 10.1108/JMTM-10-2020-0382.
[50] M. K. Kazi, F. Eljack, and E. Mahdi, "Data-driven modeling to predict the load vs. displacement curves of targeted composite materials for industry 4.0 and smart manufacturing," *Compos. Struct.*, vol. 258, no. October 2020, p. 113207, 2021, doi: 10.1016/j.compstruct.2020.113207.
[51] S. Kumar, M. Suhaib, and M. Asjad, "Narrowing the barriers to Industry 4.0 practices through PCA-Fuzzy AHP-K means," *J. Adv. Manag. Res.*, 2020, doi: 10.1108/JAMR-06-2020-0098.
[52] L. Li, F. Su, W. Zhang, and J. Y. Mao, "Digital transformation by SME entrepreneurs: A capability perspective," *Inf. Syst. J.*, vol. 28, no. 6, pp. 1129–1157, 2018, doi: 10.1111/isj.12153.
[53] A. G. Khanzode, P. R. S. Sarma, S. K. Mangla, and H. Yuan, "Modeling the Industry 4.0 adoption for sustainable production in Micro, Small & Medium

Enterprises," *J. Clean. Prod.*, vol. 279, p. 123489, 2021, doi: 10.1016/j.jclepro.2020.123489.

[54] S. M. Kannan *et al.*, "Towards industry 4.0: Gap analysis between current automotive MES and industry standards using model-based requirement engineering," *Proc. - 2017 IEEE Int. Conf. Softw. Archit. Work. ICSAW 2017 Side Track Proc.*, vol. 0, pp. 29–35, 2017, doi: 10.1109/ICSAW.2017.53.

[55] N. Grufman, S. Lyons, and E. Sneiders, "Exploring Readiness of SMEs for Industry 4.0," *Complex Syst. Informatics Model. Q.*, no. 25, pp. 54–86, 2020, doi: 10.7250/csimq.2020-25.04.

[56] M. Estensoro, M. Larrea, J. M. Müller, and E. Sisti, "A resource-based view on SMEs regarding the transition to more sophisticated stages of industry 4.0," *Eur. Manag. J.*, no. xxxx, 2021, doi: 10.1016/j.emj.2021.10.001.

[57] S. R. Hamidi, A. A. Aziz, S. M. Shuhidan, A. A. Aziz, and M. Mokhsin, "SMEs maturity model assessment of IR4.0 digital transformation," *Adv. Intell. Syst. Comput.*, vol. 739, pp. 721–732, 2018, doi: 10.1007/978-981-10-8612-0_75.

[58] D. Zuhlke, *SmartFactory - A vision becomes reality*, vol. 13, no. PART 1. IFAC, 2009.

[59] J. El Baz, S. Tiwari, T. Akenroye, A. Cherrafi, and R. Derrouiche, "A framework of sustainability drivers and externalities for Industry 4.0 technologies using the Best-Worst Method," *J. Clean. Prod.*, vol. 344, no. October 2021, p. 130909, 2022, doi: 10.1016/j.jclepro.2022.130909.

[60] L. T. Letchumanan *et al.*, "Analyzing the Factors Enabling Green Lean Six Sigma Implementation in the Industry 4.0 Era," *Sustain.*, vol. 14, no. 6, pp. 1–15, 2022, doi: 10.3390/su14063450.

[61] Z. Liu *et al.*, "The architectural design and implementation of a digital platform for Industry 4.0 SME collaboration," *Comput. Ind.*, vol. 138, p. 103623, 2022, doi: 10.1016/j.compind.2022.103623.

[62] F. Longo, L. Nicoletti, and A. Padovano, "Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context," *Comput. Ind. Eng.*, vol. 113, pp. 144–159, 2017, doi: 10.1016/j.cie.2017.09.016.

[63] F. Dillinger, O. Bernhard, M. Kagerer, and G. Reinhart, "Industry 4.0 implementation sequence for manufacturing companies," *Prod. Eng.*, no. 0123456789, 2022, doi: 10.1007/s11740-022-01110-5.

[64] V. Jain and P. Ajmera, "Modelling the enablers of industry 4.0 in the Indian manufacturing industry," *Int. J. Product. Perform. Manag.*, 2020, doi: 10.1108/IJPPM-07-2019-0317.

[65] A. Amaral and P. Peças, "A framework for assessing manufacturing smes industry 4.0 maturity," *Appl. Sci.*, vol. 11, no. 13, 2021, doi: 10.3390/app11136127.

[66] L. Bosman, N. Hartman, and J. Sutherland, "How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies," *J. Manuf. Technol. Manag.*, vol. 31, no. 5, pp. 1117–1141, 2019, doi: 10.1108/JMTM-09-2018-0283.

[67] D. Lucke, C. Constantinescu, and E. Westkämper, "Smart Factory - A Step towards the Next Generation of Manufacturing," *Manuf. Syst. Technol. New Front.*, no. Sfb 627, pp. 115–118, 2008, doi: 10.1007/978-1-84800-267-8_23.

[68] S. C. Lee, T. G. Jeon, H. S. Hwang, and C. S. Kim, "Design and implementation of wireless sensor based-monitoring system for smart factory," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 4706 LNCS, no. PART 2, pp. 584–592, 2007, doi: 10.1007/978-3-540-744 77-1_54.

[69] J. C. Serrano-Ruiz, J. Mula, and R. Poler, "Toward smart manufacturing scheduling from an ontological approach of job-shop uncertainty sources," *IFAC-PapersOnLine*, vol. 55, no. 2, pp. 150–155, 2022, doi: 10.1016/j.ifacol.2022.04.185.

[70] S. Paasche and S. Groppe, *Enhancing data quality and process optimization for smart manufacturing lines in industry 4.0 scenarios*, vol. 1, no. 1. Association for Computing Machinery, 2022.

[71] Y. Lu and F. Ju, "Smart Manufacturing Systems based on Cyber-physical Manufacturing Services (CPMS)," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 15883–15889, 2017, doi: 10.1016/j.ifacol.2017.08.2349.

[72] G. Shao, S. Jain, C. Laroque, L. H. Lee, P. Lendermann, and O. Rose, "Digital Twin for Smart Manufacturing: The Simulation Aspect," *Proc. - Winter Simul. Conf.*, vol. 2019-Decem, no. Bolton 2016, pp. 2085–2098, 2019, doi: 10.1109/WSC40007.2019.9004659.

[73] M. Trstenjak, D. Lisjak, T. Opetuk, and D. Pavković, "Application of multi criteria decision making methods for readiness factor calculation," *EUROCON 2019 - 18th Int. Conf. Smart Technol.*, pp. 1–6, 2019, doi: 10.1109/EUROCON.2019.8861520.

[74] C. Faller and D. Feldmúller, "Industry 4.0 learning factory for regional SMEs," *Procedia CIRP*, vol. 32, no. Clf, pp. 88–91, 2015, doi: 10.1016/j.procir.2015.02.117.

[75] S. I. Shafiq, G. Velez, C. Toro, C. Sanin, and E. Szczerbicki, "Designing intelligent factory: Conceptual framework and empirical validation," *Procedia Comput. Sci.*, vol. 96, pp. 1801–1808, 2016, doi: 10.1016/j.procs.2016.09.351.

[76] B. Hameed *et al.*, "Functional Thinking for Value Creation," *Funct. Think. Value Creat.*, pp. 326–331, 2011, doi: 10.1007/978-3-642-19689-8.

[77] M. G. Seok, W. J. Tan, B. Su, and W. Cai, "Hyperparameter Tunning in Simulation-based Optimization for Adaptive Digital-Twin Abstraction Control of Smart Manufacturing System," in *SIGSIM Con-ference on Principles ofAdvanced Discrete Simulation*, 2022, pp. 61–68, doi: 10.1145/3518997.3531024.

[78] G. Saravanan, S. S. Parkhe, C. M. Thakar, V. V. Kulkarni, H. G. Mishra, and G. Gulothungan, "Implementation of IoT in production and manufacturing: An Industry 4.0 approach," *Mater. Today Proc.*, vol. 51, pp. 2427–2430, 2022, doi: 10.1016/j.matpr.2021.11.604.

[79] J. Lee, M. Azamfar, J. Singh, and S. Siahpour, "Integration of digital twin and deep learning in cyber-physical systems: Towards smart manufacturing," *IET Collab. Intell. Manuf.*, vol. 2, no. 1, pp. 34–36, 2020, doi: 10.1049/iet-cim.2020.0009.

[80] F. Simetinger and Z. Zhang, "Deriving secondary traits of industry 4.0: A comparative analysis of significant maturity models," *Syst. Res. Behav. Sci.*, vol. 37, no. 4, pp. 663–678, 2020, doi: 10.1002/sres.2708.

[81] S. Wang, J. Wan, D. Zhang, D. Li, and C. Zhang, "Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination," *Comput. Networks*, vol. 101, pp. 158–168, 2016, doi: 10.1016/j.comnet.2015.12.017.

[82] James, T. "Smart factories," *Engineering & technology*, vol. 7, no. 6, pp. 64–67, 2012.

[83] F. E. Gruber, "Industry 4.0: A best practice project of the automotive industry," *IFIP Adv. Inf. Commun. Technol.*, vol. 411, pp. 36–40, 2013, doi: 10.1007/978-3-642-41329-2_5.

[84] H. Lasi, P. Fettke, H. G. Kemper, T. Feld, and M. Hoffmann, "Industry 4.0," *Bus. Inf. Syst. Eng.*, vol. 6, no. 4, pp. 239–242, 2014, doi: 10.1007/s12599-014-0334-4.

[85] T. P. Cunha, M. P. Méxas, A. Cantareli da Silva, and O. L. Gonçalves Quelhas, "Proposal guidelines to implement the concepts of industry 4.0 into information technology companies," *TQM J.*, vol. 32, no. 4, pp. 741–759, 2020, doi: 10.1108/TQM-10-2019-0249.

[86] N. Chonsawat, "Defining SMEs' 4.0 Readiness Indicators Nilubon," *Appl. Sci.*, pp. 124–134, 2018.
[87] P. Dhamija and S. Bag, "Role of artificial intelligence in operations environment: a review and bibliometric analysis," *TQM J.*, vol. 32, no. 4, pp. 869–896, 2020, doi: 10.1108/TQM-10-2019-0243.
[88] D. Chen, T. Kjellberg, and A. Von Euler, "Software tools for the digital factory - An evaluation and discussion," *Adv. Intell. Soft Comput.*, vol. 66 AISC, pp. 803–812, 2010, doi: 10.1007/978-3-642-10430-5_62.
[89] M. Asif Rashid, H. Qureshi, M.-D. Shami, and N. Khan, "ERP Lifecycle Management for Aerospace Smart Factory: A Multidisciplinary Approach," *Int. J. Comput. Appl.*, vol. 26, no. 11, pp. 55–62, 2011, doi: 10.5120/3171-4372.
[90] B. J. Van Putten, M. Kuestner, and M. Rosjat, "The future factory initiative at SAP research," *ETFA 2009 - 2009 IEEE Conf. Emerg. Technol. Fact. Autom.*, pp. 5–8, 2009, doi: 10.1109/ETFA.2009.5347257.
[91] Weyer, S., Schmitt, M., Ohmer, M., and Gorecky, D. "Towards Industry 4.0-Standardization as the crucial challenge for highly modular, multi-vendor production systems," *Ifac-Papersonline*, vol. 48, no. 3, pp. 579–584, 2015.
[92] S. Chou, "The fourth industrial revolution: digital fusion with internet of things," *J. Int. Aff.*, vol. 72, no. 1, pp. 107–120, 2016.
[93] Frank, A. G., Dalenogare, L. S., and Ayala, N. F. "Industry 4.0 technologies: Implementation patterns in manufacturing companies," *International Journal of Production Economics*, vol. 210, pp. 15–26, 2019.
[94] F. Tao, H. Zhang, A. Liu and A. Y. C. Nee, "Digital Twin in Industry: State-of-the-Art," in *IEEE Transactions on Industrial Informatics*, vol. 15, no. 4, pp. 2405–2415, April 2019, doi: 10.1109/TII.2018.2873186.
[95] Lopes de Sousa Jabbour, A.B., Jabbour, C.J.C., Godinho Filho, M. et al., "Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations," *Ann Oper Res*, vol. 270, pp. 273–286, 2018. 10.1007/s10479-018-2772-8
[96] Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., and Barbaray, R. "The industrial management of SMEs in the era of Industry 4.0," *International journal of production research*, vol. 56, no. 3, pp. 1118–1136, 2018.
[97] Buer, S. V., Strandhagen, J. O., and Chan, F. T. "The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda," *International journal of production research*, vol. 56, no. 8, pp. 2924–2940, 2018.
[98] Mittal, S., Khan, M. A., Romero, D., and Wuest, T. "Smart manufacturing: Characteristics, technologies and enabling factors." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 233, no. 5, 1342–1361, 2019.
[99] Fatorachian, H., and Kazemi, H. "A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework." *Production Planning & Control*, vol. 29, no. 8, 633–644, 2018.
[100] Qin, J., Liu, Y., and Grosvenor, R. "A categorical framework of manufacturing for industry 4.0 and beyond," *Procedia cirp*, vol. 52, 173–178, 2016.
[101] Jung, K., Kulvatunyou, B., Choi, S., and Brundage, M. P. "An overview of a smart manufacturing system readiness assessment. In Advances in Production Management Systems," Initiatives for a Sustainable World: IFIP WG 5.7 International Conference, APMS 2016, Iguassu Falls, Brazil, September 3–7, 2016, Revised Selected Papers (pp. 705–712), 2016. Springer International Publishing.

APPENDIX

TABLE A1
Quality Evaluation Score (QES) of Some Studies

Author/Year	QEP1	QEP2	QEP3	QEP4	QEP5	QEP6	QEP7	QES Score
Lee et al., 2007	0	1	0	0	1	1	1	4
Lucke et al., 2008	1	1	0	1	1	0	1	5
Zühlke, 2009	1	1	0	1	0	0	0	3
James, 2012	1	1	1	0	0	1	1	5
Gruber, 2013	0	1	1	1	1	1	0	5
Lasi et al., 2014	0	1	1	1	0	1	1	5
Faller and Feldmüller, 2015	0	1	1	1	0	1	0	4
Weyer et al., 2015	0	1	1	1	1	1	0	5
Li, 2016	0	1	1	1	1	1	1	6
Lu and Ju, 2017	0	1	1	1	1	1	0	5
Iyer, 2018	1	1	0	1	1	1	0	5
Bibby and Dehe, 2018	1	1	0	1	1	1	1	6
Hamidi et al., 2018	1	1	1	1	1	1	1	7
Horvat et al., 2018	1	1	1	1	1	0	0	5
Chou, 2018	1	1	1	1	1	1	0	6
Simetinger and Zhang, 2020	1	1	1	1	1	0	0	5
Bachinger and Kronberger, 2021	1	1	0	1	1	0	1	5
Paasche and Groppe, 2022	1	1	1	1	1	1	0	6
Liu et al., 2022	0	1	1	1	1	0	1	5

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J. Davis *et al.* , Smart Manufacturing, Annu. Rev. Chem. Biomol. Eng., vol. 6, no. April, pp. 141–160, 2015, doi: 10.1146/annurev-chembioeng-061114-123255.

S. Phuyal , D. Bista , and R. Bista , Challenges, Opportunities and Future Directions of Smart Manufacturing: A State of Art Review, Sustain. Futur., vol. 2, no. March, p. 100023, 2020, doi: 10.1016/j.sftr.2020.100023.

F. Bachinger , G. Kronberger , and M. Affenzeller , Continuous improvement and adaptation of predictive models in smart manufacturing and model management, IET Collab. Intell. Manuf., vol. 3, no. 1, pp. 48–63, 2021, doi: 10.1049/cim2.12009.

M. Shahin , F. F. Chen , H. Bouzary , and K. Krishnaiyer , Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises, Int. J. Adv. Manuf. Technol., vol. 107, no. 5–6, pp. 2927–2936, 2020, doi: 10.1007/s00170-020-05124-0.

J. M. Müller , O. Buliga , and K. I. Voigt , The role of absorptive capacity and innovation strategy in the design of industry 4.0 business Models - A comparison between SMEs and large enterprises, Eur. Manag. J., vol. 39, no. 3, pp. 333–343, 2021, doi: 10.1016/j.emj.2020.01.002.

A. Felsberger , F. Hasan Qaiser , A. Chaudhary , and G. Reiner , Felsberger et al. The impact of Industry 4.0 on the reconciliation of dynamic capabilities evidence from the European manufacturing indu-annotated.pdf, Prod. Plan. Control, vol. 33, no. 2–3, pp. 277–300, 2022, doi: 10.1080/09537287.2020.1810765.

M. Ghobakhloo and M. Iranmanesh , Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs, J. Manuf. Technol. Manag., vol. 32, no. 8, pp. 1533–1556, 2021, doi: 10.1108/JMTM-11-2020-0455.

M. Ghobakhloo , Industry 4.0, digitization, and opportunities for sustainability, J. Clean. Prod., vol. 252, p. 119869, 2020, doi: 10.1016/j.jclepro.2019.119869.

S. V. Shet and V. Pereira , Proposed managerial competencies for Industry 4.0 – Implications for social sustainability, Technol. Forecast. Soc. Change, vol. 173, no. March, p. 121080, 2021, doi: 10.1016/j.techfore.2021.121080.

B. Bajic , A. Rikalovic , N. Suzic , and V. Piuri , Industry 4.0 Implementation Challenges and Opportunities: A Managerial Perspective, IEEE Syst. J., vol. 15, no. 1, pp. 546–559, 2021, doi: 10.1109/JSYST.2020.3023041.

A. Raj , G. Dwivedi , A. Sharma , A. B. Lopes de Sousa Jabbour , and S. Rajak , Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective, Int. J. Prod. Econ., vol. 224, no. August 2019, p. 107546, 2020, doi: 10.1016/j.ijpe.2019.107546.

G. Orzes , E. Rauch , S. Bednar , and R. Poklemba , Industry 4.0 Implementation Barriers in Small and Medium Sized Enterprises: A Focus Group Study, IEEE Int. Conf. Ind. Eng. Eng. Manag., vol. 2019-Decem, pp. 1348–1352, 2019, doi: 10.1109/IEEM.2018.8607477.

A. G. Frank , L. S. Dalenogare , and N. F. Ayala , Industry 4.0 technologies: Implementation patterns in manufacturing companies, Int. J. Prod. Econ., vol. 210, no. September 2018, pp. 15–26, 2019, doi: 10.1016/j.ijpe.2019.01.004.

K. Zhou , T. Liu , and L. Zhou , Industry 4.0: Towards future industrial opportunities and challenges, *2015 12th Int. Conf. Fuzzy Syst. Knowl. Discov. FSKD 2015* , pp. 2147–2152, 2016, doi: 10.1109/FSKD.2015.7382284.

A. Issa , B. Hatiboglu , A. Bildstein , and T. Bauernhansl , Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment, Procedia CIRP, vol. 72, pp. 973–978, 2018, doi: 10.1016/j.procir.2018.03.151.

K. Y. Akdil , A. Ustundag , and E. Cevikcan , Maturity and Readiness Model for Industry 4.0 Strategy. 2018.

L. Bibby and B. Dehe , Defining and assessing industry 4.0 maturity levels–case of the defence sector, Prod. Plan. Control, vol. 29, no. 12, pp. 1030–1043, 2018, doi: 10.1080/09537287.2018.1503355.

K. Lichtblau *et al.* , IMPULS-Industrie 4.0-Readiness, 2015.

K. Petersen , S. Vakkalanka , and L. Kuzniarz , Guidelines for conducting systematic mapping studies in software engineering: An update, Inf. Softw. Technol., vol. 64, pp. 1–18, 2015, doi: 10.1016/j.infsof.2015.03.007.

Y. J. Qu , X. G. Ming , Z. W. Liu , X. Y. Zhang , and Z. T. Hou , Smart manufacturing systems: state of the art and future trends, Int. J. Adv. Manuf. Technol., vol. 103, no. 9–12, pp. 3751–3768, 2019, doi: 10.1007/s00170-019-03754-7.

K. Elibal and E. Özceylan , A systematic literature review for industry 4.0 maturity modeling: state-of-the-art and future challenges, Kybernetes, vol. 50, no. 11, pp. 2957–2994, 2021, doi: 10.1108/K-07-2020-0472.

M. Hizam-Hanafiah , M. A. Soomro , and N. L. Abdullah , Industry 4.0 Readiness Models.Pdf, 2020.

S. S. Kamble , A. Gunasekaran , and S. A. Gawankar , Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives, Process Saf. Environ. Prot., vol. 117, pp. 408–425, 2018, doi: 10.1016/j.psep.2018.05.009.

Y. Liao , F. Deschamps , E. De F. R. Loures , and L. F. P. Ramos , Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal, Int. J. Prod. Res., vol. 55, no. 12, pp. 3609–3629, 2017, doi: 10.1080/00207543.2017.1308576.

A. A. Khan , J. W. Keung , Fazal-E-Amin , and M. Abdullah-Al-Wadud , Spiimm: Toward a model for software process improvement implementation and management in global software development, IEEE Access, vol. 5, no. c, pp. 13720–13741, 2017, doi: 10.1109/ACCESS.2017.2728603.

Aria, M. and Cuccurullo, C. Bibliometrix: An R-tool for comprehensive science mapping analysis, Journal of Informetrics, vol. 11, no. 4, pp. 959–975, 2017.

B. Kitchenham and S. M. Charters , Guidelines for performing Systematic Literature Reviews in Software Engineering Guidelines for performing Systematic Literature Reviews in Software Engineering EBSE Technical Report EBSE-2007-01 Software Engineering Group School of Computer Science and Ma, no. January, 2007.

M. B. Eriksen and T. F. Frandsen , The impact of patient, intervention, comparison, outcome (PICO) as a search strategy tool on literature search quality: a systematic review, vol. 106, no. October, pp. 420–431, 2018.

S. R. Bin Rahamaddulla , Z. Leman , B. T. H. T. Bin Baharudin , and S. A. Ahmad , Conceptualizing smart manufacturing readiness-maturity model for small and medium enterprise (Sme) in malaysia, Sustain., vol. 13, no. 17, pp. 1–18, 2021, doi: 10.3390/su13179793.

C. Swarnima , P. Mehra , and A. Dasot , India's Readiness for Industry 4.0 – A Focus on Automotive Sector, Grant Thornt. Indian, p. 46, 2017, [Online]. Available: http://www.grantthornton.in/insights/articles/indias-readiness-for-industry-4.0--a-focus-on-automotive-sector/.

S. M. Saad , R. Bahadori , and H. Jafarnejad , The smart SME technology readiness assessment methodology in the context of industry 4.0, J. Manuf. Technol. Manag., vol. 32, no. 5, pp. 1037–1065, 2021, doi: 10.1108/JMTM-07-2020-0267.

M. M. Queiroz , S. C. F. Pereira , R. Telles , and M. C. Machado , Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities, Benchmarking, 2019, doi: 10.1108/BIJ-12-2018-0435.

E. Rauch , P. Dallasega , and M. Unterhofer , Requirements and Barriers for Introducing Smart Manufacturing in Small and Medium-Sized Enterprises, IEEE Eng. Manag. Rev., vol. 47, no. 3, pp. 87–94, 2019, doi: 10.1109/EMR.2019.2931564.

Z. Suleiman , S. Shaikholla , D. Dikhanbayeva , E. Shehab , and A. Turkyilmaz , Industry 4.0-Clustering of concepts and characteristics, cogent Eng., vol. 9, no. 1, p. 2034264, 2022.

F. Tao , Q. Qi , L. Wang , and A. Y. C. Nee , Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison, Engineering, vol. 5, no. 4, pp. 653–661, 2019, doi: 10.1016/j.eng.2019.01.014.

K. Traganos , P. Grefen , I. Vanderfeesten , J. Erasmus , G. Boultadakis , and P. Bouklis , The HORSE framework: A reference architecture for cyber-physical systems in hybrid smart manufacturing, J. Manuf. Syst., vol. 61, no. October, pp. 461–494, 2021, doi: 10.1016/j.jmsy.2021.09.003.

E. Pessl , S. R. Sorko , and B. Mayer , Roadmap industry 4.0 - Implementation guideline for enterprises, Int. J. Sci. Technol. Soc., vol. 5, no. 6, pp. 193–202, 2017, doi: 10.11648/j.ijsts.20170506.14.

D. Guo *et al.* , Synchroperation in industry 4.0 manufacturing, Int. J. Prod. Econ., vol. 238, no. March, p. 108171, 2021, doi: 10.1016/j.ijpe.2021.108171.

S. Krishnan , S. Gupta , M. Kaliyan , V. Kumar , and J. A. Garza-Reyes , Assessing the key enablers for Industry 4.0 adoption using MICMAC analysis: a case study, Int. J. Product. Perform. Manag., vol. 70, no. 5, pp. 1049–1071, 2021, doi: 10.1108/IJPPM-02-2020-0053.

D. Horvat , T. Stahlecker , A. Zenker , C. Lerch , and M. Mladineo , A conceptual approach to analysing manufacturing companies' profiles concerning Industry 4.0 in emerging economies, Procedia Manuf., vol. 17, pp. 419–426, 2018, doi: 10.1016/j.promfg.2018.10.065.

J. C. Serrano-Ruiz , J. Mula , and R. Poler , Development of a multidimensional conceptual model for job shop smart manufacturing scheduling from the Industry 4.0 perspective, J. Manuf. Syst., vol. 63, no. January, pp. 185–202, 2022, doi: 10.1016/j.jmsy.2022.03.011.

G. Liu *et al.* , Two-stage Competitive Particle Swarm Optimization Based Timing-driven X-routing for IC Design under Smart Manufacturing, ACM Trans. Manag. Inf. Syst., 2022, doi: 10.1145/3531328.

D. Li , Perspective for smart factory in petrochemical industry, Comput. Chem. Eng., vol. 91, pp. 136–148, 2016, doi: 10.1016/j.compchemeng.2016.03.006.

A. Iyer , Moving from Industry 2.0 to Industry 4.0: A case study from India on leapfrogging in smart manufacturing, Procedia Manuf., vol. 21, pp. 663–670, 2018, doi: 10.1016/j.promfg.2018.02.169.

F. Pirola , C. Cimini , and R. Pinto , Digital readiness assessment of Italian SMEs: a case-study research, J. Manuf. Technol. Manag., vol. 31, no. 5, pp. 1045–1083, 2019, doi: 10.1108/JMTM-09-2018-0305.

S. Parhi , K. Joshi , T. Wuest , and M. Akarte , Factors affecting Industry 4.0 adoption – A hybrid SEM-ANN approach, Comput. Ind. Eng., vol. 168, no. March 2021, p. 108062, 2022, doi: 10.1016/j.cie.2022.108062.

F. Nwaiwu , M. Duduci , F. Chromjakova , and C. A. F. Otekhile , Industry 4.0 concepts within the czech sme manufacturing sector: An empirical assessment of critical success factors, Bus. Theory Pract., vol. 21, no. 1, pp. 58–70, 2020, doi: 10.3846/btp.2020.10712.

H. Wang and B. Lin , Pipelined van Emde Boas tree: Algorithms, analysis, and applications, *Proc. – IEEE INFOCOM* , pp. 2471–2475, 2007, doi: 10.1109/INFCOM.2007.303.

M. Lassnig , J. M. Müller , K. Klieber , A. Zeisler , and M. Schirl , A digital readiness check for the evaluation of supply chain aspects and company size for Industry 4.0, J. Manuf. Technol. Manag., vol. 33, no. 9, pp. 1–18, 2018, doi: 10.1108/JMTM-10-2020-0382.

M. K. Kazi , F. Eljack , and E. Mahdi , Data-driven modeling to predict the load vs. displacement curves of targeted composite materials for industry 4.0 and smart manufacturing, Compos. Struct., vol. 258, no. October 2020, p. 113207, 2021, doi: 10.1016/j.compstruct.2020.113207.

S. Kumar , M. Suhaib , and M. Asjad , Narrowing the barriers to Industry 4.0 practices through PCA-Fuzzy AHP-K means, J. Adv. Manag. Res., 2020, doi: 10.1108/JAMR-06-2020-0098.

L. Li , F. Su , W. Zhang , and J. Y. Mao , Digital transformation by SME entrepreneurs: A capability perspective, Inf. Syst. J., vol. 28, no. 6, pp. 1129–1157, 2018, doi: 10.1111/isj.12153.

A. G. Khanzode , P. R. S. Sarma , S. K. Mangla , and H. Yuan , Modeling the Industry 4.0 adoption for sustainable production in Micro, Small & Medium Enterprises, J. Clean. Prod., vol. 279, p. 123489, 2021, doi: 10.1016/j.jclepro.2020.123489.

S. M. Kannan *et al.* , Towards industry 4.0: Gap analysis between current automotive MES and industry standards using model-based requirement engineering, Proc. - 2017 IEEE Int. Conf. Softw. Archit. Work. ICSAW 2017 Side Track Proc., vol. 0, pp. 29–35, 2017, doi: 10.1109/ICSAW.2017.53.

N. Grufman , S. Lyons , and E. Sneiders , Exploring Readiness of SMEs for Industry 4.0, Complex Syst. Informatics Model. Q., no. 25, pp. 54–86, 2020, doi: 10.7250/csimq.2020-25.04.

M. Estensoro , M. Larrea , J. M. Müller , and E. Sisti , A resource-based view on SMEs regarding the transition to more sophisticated stages of industry 4.0, Eur. Manag. J., no. xxxx, 2021, doi: 10.1016/j.emj.2021.10.001.

S. R. Hamidi , A. A. Aziz , S. M. Shuhidan , A. A. Aziz , and M. Mokhsin , SMEs maturity model assessment of IR4.0 digital transformation, Adv. Intell. Syst. Comput., vol. 739, pp. 721–732, 2018, doi: 10.1007/978-981-10-8612-0_75.

D. Zuhlke , SmartFactory - A vision becomes reality, vol. 13, no. PART 1. IFAC, 2009.

J. El Baz , S. Tiwari , T. Akenroye , A. Cherrafi , and R. Derrouiche , A framework of sustainability drivers and externalities for Industry 4.0 technologies using the Best-Worst Method, J. Clean. Prod., vol. 344, no. October 2021, p. 130909, 2022, doi: 10.1016/j.jclepro.2022.130909.

L. T. Letchumanan *et al.* , Analyzing the Factors Enabling Green Lean Six Sigma Implementation in the Industry 4.0 Era, Sustain., vol. 14, no. 6, pp. 1–15, 2022, doi: 10.3390/su14063450.

Z. Liu *et al*. , The architectural design and implementation of a digital platform for Industry 4.0 SME collaboration, Comput. Ind., vol. 138, p. 103623, 2022, doi: 10.1016/j.compind.2022.103623.

F. Longo , L. Nicoletti , and A. Padovano , Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context, Comput. Ind. Eng., vol. 113, pp. 144–159, 2017, doi: 10.1016/j.cie.2017.09.016.

F. Dillinger , O. Bernhard , M. Kagerer , and G. Reinhart , Industry 4.0 implementation sequence for manufacturing companies, Prod. Eng., no. 0123456789, 2022, doi: 10.1007/s11740-022-01110-5.

V. Jain and P. Ajmera , Modelling the enablers of industry 4.0 in the Indian manufacturing industry, Int. J. Product. Perform. Manag., 2020, doi: 10.1108/IJPPM-07-2019-0317.

A. Amaral and P. Peças , A framework for assessing manufacturing smes industry 4.0 maturity, Appl. Sci., vol. 11, no. 13, 2021, doi: 10.3390/app11136127.

L. Bosman , N. Hartman , and J. Sutherland , How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies, J. Manuf. Technol. Manag., vol. 31, no. 5, pp. 1117–1141, 2019, doi: 10.1108/JMTM-09-2018-0283.

D. Lucke , C. Constantinescu , and E. Westkämper , Smart Factory - A Step towards the Next Generation of Manufacturing, Manuf. Syst. Technol. New Front., no. Sfb 627, pp. 115–118, 2008, doi: 10.1007/978-1-84800-267-8_23.

S. C. Lee , T. G. Jeon , H. S. Hwang , and C. S. Kim , Design and implementation of wireless sensor based-monitoring system for smart factory, Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 4706 LNCS, no. PART 2, pp. 584–592, 2007, doi: 10.1007/978-3-540-74477-1_54.

J. C. Serrano-Ruiz , J. Mula , and R. Poler , Toward smart manufacturing scheduling from an ontological approach of job-shop uncertainty sources, IFAC-PapersOnLine, vol. 55, no. 2, pp. 150–155, 2022, doi: 10.1016/j.ifacol.2022.04.185.

S. Paasche and S. Groppe , Enhancing data quality and process optimization for smart manufacturing lines in industry 4.0 scenarios, vol. 1, no. 1. Association for Computing Machinery, 2022.

Y. Lu and F. Ju , Smart Manufacturing Systems based on Cyber-physical Manufacturing Services (CPMS), IFAC-PapersOnLine, vol. 50, no. 1, pp. 15883–15889, 2017, doi: 10.1016/j.ifacol.2017.08.2349.

G. Shao , S. Jain , C. Laroque , L. H. Lee , P. Lendermann , and O. Rose , Digital Twin for Smart Manufacturing: The Simulation Aspect, Proc. - Winter Simul. Conf., vol. 2019-Decem, no. Bolton 2016, pp. 2085–2098, 2019, doi: 10.1109/WSC40007.2019.9004659.

M. Trstenjak , D. Lisjak , T. Opetuk , and D. Pavković , Application of multi criteria decision making methods for readiness factor calculation, *EUROCON 2019 - 18th Int. Conf. Smart Technol* ., pp. 1–6, 2019, doi: 10.1109/EUROCON.2019.8861520.

C. Faller and D. Feldmúller , Industry 4.0 learning factory for regional SMEs, Procedia CIRP, vol. 32, no. Clf, pp. 88–91, 2015, doi: 10.1016/j.procir.2015.02.117.

S. I. Shafiq , G. Velez , C. Toro , C. Sanin , and E. Szczerbicki , Designing intelligent factory: Conceptual framework and empirical validation, Procedia Comput. Sci., vol. 96, pp. 1801–1808, 2016, doi: 10.1016/j.procs.2016.09.351.

B. Hameed *et al*. , Functional Thinking for Value Creation, Funct. Think. Value Creat., pp. 326–331, 2011, doi: 10.1007/978-3-642-19689-8.

M. G. Seok , W. J. Tan , B. Su , and W. Cai , Hyperparameter Tunning in Simulation-based Optimization for Adaptive Digital-Twin Abstraction Control of Smart Manufacturing System, in *SIGSIM Con-ference on Principles ofAdvanced Discrete Simulation* , 2022, pp. 61–68, doi: 10.1145/3518997.3531024.

G. Saravanan , S. S. Parkhe , C. M. Thakar , V. V. Kulkarni , H. G. Mishra , and G. Gulothungan , Implementation of IoT in production and manufacturing: An Industry 4.0 approach, Mater. Today Proc., vol. 51, pp. 2427–2430, 2022, doi: 10.1016/j.matpr.2021.11.604.

J. Lee , M. Azamfar , J. Singh , and S. Siahpour , Integration of digital twin and deep learning in cyber-physical systems: Towards smart manufacturing, IET Collab. Intell. Manuf., vol. 2, no. 1, pp. 34–36, 2020, doi: 10.1049/iet-cim.2020.0009.

F. Simetinger and Z. Zhang , Deriving secondary traits of industry 4.0: A comparative analysis of significant maturity models, Syst. Res. Behav. Sci., vol. 37, no. 4, pp. 663–678, 2020, doi: 10.1002/sres.2708.

S. Wang , J. Wan , D. Zhang , D. Li , and C. Zhang , Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination, Comput. Networks, vol. 101, pp. 158–168, 2016, doi: 10.1016/j.comnet.2015.12.017.

James, T. Smart factories, Engineering & technology, vol. 7, no. 6, pp. 64–67, 2012.

F. E. Gruber , Industry 4.0: A best practice project of the automotive industry, IFIP Adv. Inf. Commun. Technol., vol. 411, pp. 36–40, 2013, doi: 10.1007/978-3-642-41329-2_5.

H. Lasi , P. Fettke , H. G. Kemper , T. Feld , and M. Hoffmann , Industry 4.0, Bus. Inf. Syst. Eng., vol. 6, no. 4, pp. 239–242, 2014, doi: 10.1007/s12599-014-0334-4.

T. P. Cunha , M. P. Méxas , A. Cantareli da Silva , and O. L. Gonçalves Quelhas , Proposal guidelines to implement the concepts of industry 4.0 into information technology companies, TQM J., vol. 32, no. 4, pp. 741–759, 2020, doi: 10.1108/TQM-10-2019-0249.

N. Chonsawat , Defining SMEs' 4.0 Readiness Indicators Nilubon, Appl. Sci., pp. 124–134, 2018.

P. Dhamija and S. Bag , Role of artificial intelligence in operations environment: a review and bibliometric analysis, TQM J., vol. 32, no. 4, pp. 869–896, 2020, doi: 10.1108/TQM-10-2019-0243.

D. Chen , T. Kjellberg , and A. Von Euler , Software tools for the digital factory - An evaluation and discussion, Adv. Intell. Soft Comput., vol. 66 AISC, pp. 803–812, 2010, doi: 10.1007/978-3-642-10430-5_62.

M. Asif Rashid , H. Qureshi , M.-D. Shami , and N. Khan , ERP Lifecycle Management for Aerospace Smart Factory: A Multidisciplinary Approach, Int. J. Comput. Appl., vol. 26, no. 11, pp. 55–62, 2011, doi: 10.5120/3171-4372.

B. J. Van Putten , M. Kuestner , and M. Rosjat , The future factory initiative at SAP research, *ETFA 2009 - 2009 IEEE Conf. Emerg. Technol. Fact. Autom* ., pp. 5–8, 2009, doi: 10.1109/ETFA.2009.5347257.

Weyer, S. , Schmitt, M. , Ohmer, M. , and Gorecky, D. Towards Industry 4.0-Standardization as the crucial challenge for highly modular, multi-vendor production systems, Ifac-Papersonline, vol. 48, no. 3, pp. 579–584, 2015.

S. Chou , The fourth industrial revolution: digital fusion with internet of things, J. Int. Aff., vol. 72, no. 1, pp. 107–120, 2016.

Frank, A. G. , Dalenogare, L. S. , and Ayala, N. F. Industry 4.0 technologies: Implementation patterns in manufacturing companies, International Journal of Production Economics, vol. 210, pp. 15–26, 2019.

F. Tao , H. Zhang , A. Liu and A. Y. C. Nee , Digital Twin in Industry: State-of-the-Art, in IEEE Transactions on Industrial Informatics, vol. 15, no. 4, pp. 2405–2415, April 2019, doi: 10.1109/TII.2018.2873186.

Lopes de Sousa Jabbour, A.B. , Jabbour, C.J.C. , Godinho Filho, M. et al. , Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations, Ann Oper Res, vol. 270, pp. 273–286, 2018. 10.1007/s10479-018-2772-8

Moeuf, A. , Pellerin, R. , Lamouri, S. , Tamayo-Giraldo, S. , and Barbaray, R. The industrial management of SMEs in the era of Industry 4.0, International journal of production research, vol. 56, no. 3, pp. 1118–1136, 2018.

Buer, S. V. , Strandhagen, J. O. , and Chan, F. T. The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda, International journal of production research, vol. 56, no. 8, pp. 2924–2940, 2018.

Mittal, S. , Khan, M. A. , Romero, D. , and Wuest, T. Smart manufacturing: Characteristics, technologies and enabling factors. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 233, no. 5, 1342–1361, 2019.

Fatorachian, H. , and Kazemi, H. A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework. Production Planning & Control, vol. 29, no. 8, 633–644, 2018.

Qin, J. , Liu, Y. , and Grosvenor, R. A categorical framework of manufacturing for industry 4.0 and beyond, Procedia cirp, vol. 52, 173–178, 2016.

Jung, K. , Kulvatunyou, B. , Choi, S. , and Brundage, M. P. An overview of a smart manufacturing system readiness assessment. In Advances in Production Management Systems, Initiatives for a Sustainable World: IFIP WG 5.7 International Conference, APMS 2016, Iguassu Falls, Brazil, September 3–7, 2016, Revised Selected Papers (pp. 705–712), 2016. Springer International Publishing.

Study and Analysis of IoT (Industry 4.0)

Nardo, M. , Forino, D. , & Murino, T. 2020. The evolution of man-machine interaction: The role of human in Industry 4.0 paradigm. Production & Manufacturing Research 8(1):20–34.

Drath, R. , & Horch, A. 2014. Industrie 4.0: Hit or hype? [industry forum]. IEEE Industrial Electronics Magazine 8(2):56–58.

Sony, M. 2020. Pros and cons of implementing Industry 4.0 for the organizations: A review and synthesis of evidence. Production & Manufacturing Research 8(1):244–272.

Lee, E. A. 2008. Cyber physical systems: Design challenges. In 2008 11th IEEE International Symposium on Object and Component-Oriented Real-Time Distributed Computing (ISORC):363–369). IEEE.

Gubbi, J. , Buyya, R. , Marusic, S. , & Palaniswami, M. 2013. Internet of things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems 29(7):1645–1660.

Kusiak, A. 2018. Smart manufacturing. International Journal of Production Research 56(1–2):508–517.

Frank, A. G. , Dalenogare, L. S. , & Ayala, N. F. 2019. Industry 4.0 technologies: Implementation patterns in manufacturing companies. International Journal of Production Economics 210:15–26.

Krugh, M. , & Mears, L. 2018. A complementary cyber-human systems framework for Industry 4.0 cyber-physical systems. Manufacturing Letters 15(partB):89–92.

Kumar, R. , Haleem, A. , Garg, S. K. , & Singh, R. K. 2015. Automated guided vehicle configurations in flexible manufacturing systems: A comparative study. International Journal of Industrial and Systems Engineering 21(2):207.

Ferdows, K. , & De Meyer, A. 1990. Lasting improvements in manufacturing performance: In search of a new theory. Journal of Operations Management 9(2):168–184.

Almada-Lobo, F. 2015. The Industry 4.0 revolution and the future of Manufacturing Execution Systems (MES). Journal of Innovation Management 3(4):16–21.

Rosa, P. , Sassanelli, C. , Urbinati, A. , Chiaroni, D. , & Terzi, S. 2020. Assessing relations between Circular Economy and Industry 4.0: A systematic literature review. International Journal of Production Research 58(6):1662–1687.

Machado, C. G. , Winroth, M. P. , & Ribeiro da Silva, E. H. D. 2020. Sustainable manufacturing in Industry 4.0: An emerging research agenda. International Journal of Production Research 58(5):1462–1484.

Rosin, F. , Forget, P. , Lamouri, S. , & Pellerin, R. 2020.Impacts of Industry 4.0 technologies on Lean principles. International Journal of Production Research 58(6):1644–1661.

Sony, M. (2018). Industry 4.0 and lean management: A proposed integration model and research propositions. Production & Manufacturing Research 6(1):416–432.

Balland, P. A. , & Boschma, R. 2021. Mapping the potentials of regions in Europe to contribute to new knowledge production in Industry 4.0 technologies. Regional Studies 55(10–11):1652–1666.

Moeuf, A. , Lamouri, S. , Pellerin, R. , Tamayo-Giraldo, S. , Tobon-Valencia, E. , & Eburdy, R. 2020. Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. International Journal of Production Research 58(5):1384–1400.

Li, G. , Tan, J. , & Chaudhry, S. S. 2019. Industry 4.0 and big data innovations. Enterprise Information Systems 13(2):145–147.

Li, G. , Wang, H. , & Hardjawana, W. 2020. New advancement in information technologies for Industry 4.0. Enterprise Information Systems 14(4):402–405.

Valeske, B. , Osman, A. , Römer, F. , & Tschuncky, R. 2020. Next generation NDE sensor systems as IIoT elements of Industry 4.0. Research in Nondestructive Evaluation 31(5–6):340–369.

Recent Advances in Cybersecurity in Smart Manufacturing Systems in the Industry

Kosmowski, K. T. , Śliwiński, M. , & Piesik, J. (2019). Integrated functional safety and cybersecurity. Analysis method for smart manufacturing systems. Task Quarterly, 23(2), 177–207. 10.17466/tq2019/23.2/c

ISO/IEC TR 27019:2013: Information Technology – Security Techniques – Information Security Management Guidelines Based on ISO/IEC 27002 for Process Control Systems Specific to the Energy Utility Industry. 2013 https://www.iso.org/standard/43759.html

Lenz, J. , MacDonald, E. , Harik, R. , & Wuest, T. (2020). Optimizing smart manufacturing systems by extending the smart products paradigm to the beginning of life. Journal of Manufacturing Systems, 57, 274–286. 10.1016/j.jmsy.2020.10.001

Li, Q. , Tang, Q. , Chan, I. , Wei, H. , Pu, Y. , Jiang, H. , Li, J. , & Zhou, J. (2018). Smart manufacturing standardization: Architectures, reference models and standards framework. Computers in Industry, 101, 91–106. 10.1016/j.compind.2018.06.005

Phuyal, S. , Bista, D. , & Bista, R. (2020). Challenges, Opportunities and Future Directions of Smart Manufacturing: A State of Art Review.Sustainable Futures, Vol. 2, p.100023. 10.1016/j.sftr.2020.100023. Elsevier Ltd.

Tuptuk, N. , & Hailes, S. (2018). Security of smart manufacturing systems. Journal of Manufacturing Systems, 47, 93–106. 10.1016/j.jmsy.2018.04.007

Sahoo, S. , & Lo, C.-Y. (2022). Smart manufacturing powered by recent technological advancements: A review. Journal of Manufacturing Systems, 64, 236–250. 10.1016/j.jmsy.2022.06.008

Zarreh, A. , Saygin, C. , Wan, H. , Lee, Y. , Bracho, A. , & Nie, L. (2018). Cybersecurity analysis of smart manufacturing system using game theory approach and quantal response equilibrium. Procedia Manufacturing, 17, 1001–1008. 10.1016/j.promfg.2018.10.087

Shukla, M. , & Shankar, R. (2022). An extended technology-organization-environment framework to investigate smart manufacturing system implementation in small and medium enterprises. Computers and Industrial Engineering, 163. 10.1016/j.cie.2021.107865

Wang, B. , Tao, F. , Fang, X. , Liu, C. , Liu, Y. , & Freiheit, T. (2021). Smart Manufacturing and Intelligent Manufacturing: A Comparative Review. In Engineering (Vol. 7, Issue 6, pp. 738–757). Elsevier. 10.1016/j.eng.2020.07.017

Junior, A. A. de S. , Pio, J. L. de S. , Fonseca, J. C. , de Oliveira, M. A. , Valadares, O. C. de P. , & da Silva, P. H. S. (2021). The state of cybersecurity in smart manufacturing systems: A systematic review. European Journal of Business and Management Research, 6(6), 188–194. 10.24018/ejbmr.2021.6.6.1173

Choi, S. S. , Jung, K. , Kulvatunyou, B. , & Morris, K. C. (2016). An analysis of technologies and standards for designing smart manufacturing systems. Journal of Research of the National Institute of Standards and Technology, 121, 422–433. 10.6028/jres.121.021

Jbair, M. , Ahmad, B. , Maple, C. , & Harrison, R. (2022). Threat modelling for industrial cyber physical systems in the era of smart manufacturing. Computers in Industry, 137. 10.1016/j.compind.2022.103611

Bracho, A. , Saygin, C. , Wan, H. , Lee, Y. , & Zarreh, A. (2018). A simulation-based platform for assessing the impact of cyber-threats on smart manufacturing systems. Procedia Manufacturing. 26, 1116–1127. 10.1016/j.promfg.2018.07.148

L. J. Wells , J. A. Camelio , C. B. Williams , & J. White (2014). Cyber-physical security challenges in manufacturing systems. Manufacturing Letters, 2(2), 74–77.

Vincent, H. , Wells, L. , Tarazaga, P. , & Camelio, J. (2015). Trojan detection and side-channel analyses for cyber-security in cyber-physical manufacturing systems. Procedia Manuf., 1, 77–85.

Zeltmann, S. E. , Gupta, N. , Tsoutsos, N. G. , Maniatakos, M. , Rajendran, J. , & Karri, R. (2016). Manufacturing and security challenges in 3D printing. Jom, 68(7), 1872–1881.

Sturm, L. D. , Williams, C. B. , Camelio, J. A. , White, J. , & Parker, R. (2017). Cyber-physical vulnerabilities in additive manufacturing systems: A case study attack on the. STL file with human subjects. J. Manuf. Syst., 44, 154–164.

DeSmit, Z. , Elhabashy, A. E. , Wells, L. J. , & Camelio, J. A. (2017). An approach to cyber-physical vulnerability assessment for intelligent manufacturing systems. Journal of Manuf. Syst., 43, 339–351.

Schaefer, D. (n.d.). Lane Thames Cybersecurity for Industry 4.0 Springer Series in Advanced Manufacturing Analysis for Design and Manufacturing. http://www.springer.com/series/7113.
Ren, A. , Wu, D. , Zhang, W. , Terpenny, J. , & Liu, P. (2017). Cyber security in smart manufacturing: Survey and challenges. In H. B. Nembhard , K. Coperich , & E. Cudney (Eds.), 67th Annual Conference and Expo of the Institute of Industrial Engineers 2017. Institute of Industrial Engineers. pp. 716–721.
Gerekli, İ. , Çelik, T. Z. , & Bozkurt, İ. (2021). Industry 4.0 and smart production. TEM Journal, 10(2), 799–805. 10.18421/TEM102-37
Almaraz-Rivera, J. G. , Perez-Diaz, J. A. , & Cantoral-Ceballos, J. A. (2022 Apr 28). Transport and application layer DDoS attacks detection to iot devices by using machine learning and deep learning models. Sensors (Basel), 22(9), 3367. doi: 10.3390/s22093367. PMID: 35591056; PMCID: PMC9103313.
Zhang, D. , Wang, Q. G. , Feng, G. , Shi, Y. , & Vasilakos, A. V. (2021 Oct). A survey on attack detection, estimation and control of industrial cyber-physical systems. ISA Trans, 116, 1–16. doi: 10.1016/j.isatra.2021.01.036. Epub 2021 Jan 28. PMID: 33581894.
Lee, S. , Abdullah, A. , Jhanjhi, N. , & Kok, S. (2021 Jan 25). Classification of botnet attacks in IoT smart factory using honeypot combined with machine learning. PeerJ Comput Sci., 7, e350. doi: 10.7717/peerj-cs.350. PMID: 33817000; PMCID: PMC7924422.
Zarreh, A. , Wan, H. da , Lee, Y. , Saygin, C. , & Janahi, R. Al . (2019). Cybersecurity concerns for total productive maintenance in smart manufacturing systems. Procedia Manufacturing, 38, 532–539. 10.1016/j.promfg.2020.01.067
Moens, P. , Bracke, V. , Soete, C. , Vanden Hautte, S. , Nieves Avendano, D. , Ooijevaar, T. , Devos, S. , Volckaert, B. , & Van Hoecke, S. (2020 Aug 2). Scalable fleet monitoring and visualization for smart machine maintenance and industrial IoT applications. Sensors (Basel), 20(15), 4308. doi: 10.3390/s20154308. PMID: 32748809; PMCID: PMC7435597.
Tambare, P. , Meshram, C. , Lee, C. C. , Ramteke, R. J. , & Imoize, A. L. (2021 December 29). Performance measurement system and quality management in data-driven Industry 4.0: A Review. Sensors (Basel), 22(1), 224. doi: 10.3390/s22010224. PMID: 35009767; PMCID: PMC8749653.
Anderson R. , & Fuloria S. (2010). Security Economics and Critical National Infrastructure. In: Moore T. , Pym D. , Ioannidis C. , (Eds.), Economics of Information Security and Privacy. Springer US. pp. 55–66.
Is NERC CIP Compliance a Game? 2008 http://www:controlglobal:com/blogs/unfettered/electric-power-2008-is-nerc-cip-compliance-a-game
ISO/IEC 29180: 2012 Information Technology – Telecommunications and Information Exchange between Systems – Security Framework for Ubiquitous Sensor Networks. 2012 https://www.iso.org/standard/45259.html.
ISO/IEC 27019 Information Technology – Security Techniques – Information Security Controls for the Energy Utility Industry. 2017 https://www.iso.org/standard/68091.html
ISA99: Developing the ISA/IEC 62443 Series of Standards on Industrial Automation and Control Systems (IACS). 2017 http://isa99.isa.org/ISA9920Wiki/Home.aspx/
ISA99: Developing the Vital ISA/IEC 62443 Series of Standards on Industrial Automation and Control Systems (IACS) Security. 2001 http://isa99.isa.org/.
ISO/IEC 27033-1:2015 Preview Information technology-Security techniques – Network Security – Part 1: Overview and Concepts. 2015 https://www.iso.org/standard/63461.html.
Functional Safety and IEC 61508. 2010 http://www.iec.ch/functionalsafety/.
IEC 61784-1:2014: Industrial Communication Networks – Profiles – Part 1: Fieldbus Profiles. 2014 https://webstore.iec.ch/publication/5878
Qu, Y. J. , Ming, X. G. , Liu, Z. W. , Zhang, X. Y. , & Hou, Z. T. (2019). Smart manufacturing systems: State of the art and future trends. International Journal of Advanced Manufacturing Technology, 103(9–12), 3751–3768. 10.1007/s00170-019-03754-7
ISO/IEC 27000 Family – Information Security Management Systems. 2014 https://webstore.iec.ch/publication/5878
Piètre-Cambacédès L. , & Sitbon P. (2008). Cryptographic key management for SCADA systems – Issues and perspectives. Proceedings of the 2008 International Conference on Information Security Assurance (ISA 2008), ISA '08. Washington, DC, USA: IEEE Computer Society. pp. 156–161. 10.1109/IS.A.2008.77. ISBN 978-0-7695-3126-7.

Choi, D. , Lee, S. , Won, D. , & Kim, S. (2010). Efficient secure group communications for SCADA. IEEE Trans. Power Deliv., 25(2), 714–722. 10.1109/TPWRD.2009.2036181. ISSN 0885-8977.

Choi, D. , Kim, H. , Won, D. , & Kim, S. (2009). Advanced key-management architecture for secure SCADA communications. IEEE Trans. Power Deliv., 24(3), 1154–1163. 10.1109/TPWRD.2008.2005683. ISSN 0885-8977.

Pal, O. , Saiwan, S. , Jain, P. , Saquib, Z. , & Patel, D. (2009). Cryptographic key management for SCADA system: An architectural framework. 2009 International Conference on Advances in Computing, Control, and Telecommunication Technologies. pp. 169–174. 10.1109/ACT.2009.51

Jiang, R. , Lu, R. , Lai, C. , Luo, J. , & Shen, X. (2013). Robust group key management with revocation and collusion resistance for SCADA in smart grid. 2013 IEEE Global Communications Conference (GLOBECOM). pp. 802–807. 10.1109/GLOCOM.2013.6831171. ISSN 1930-529X.

Mrugala, K. , Tuptuk, N. , & Hailes, S. (2017). Evolving attackers against wireless sensor networks using genetic programming. IET Wirel. Sens. Syst., 7(4), 113–122. 10.1049/iet-wss.2016.0090

Mrugala, K. , Tuptuk, N. , & Hailes, S. (2016). Evolving attackers against wireless sensor networks. Genetic and Evolutionary Computation Conference, GECCO 2016, Denver, CO, USA. pp. 107–108. 10.1145/2908961.2908974

Beautement, A. , Sasse, M. A. , & Wonham, M. (2008). The compliance budget: Managing security behaviour in organisations. Proceedings of the 2008 Workshop on New Security Paradigms, NSPW '08. New York, USA. ACM. pp. 47–58. 10.1145/1595676.1595684. ISBN 978-1-60558-341-9.

Herath, T. , & Rao, H. R. (2009). Protection motivation and deterrence: A framework for security policy compliance in organizations. Eur J Inf. Syst., 18(2), 106–125. 10.1057/ejis.2009.6. ISSN 1476-9344.

White Paper: Protecting your organisation from itself, Tech. Rep. 2016.

Zhang, Y. , Xu, X. , Liu, A. , Lu, Q. , Xu, L. , & Tao, F. (2019). Blockchain-based trust mechanism for iot-based smart manufacturing system. IEEE Transactions on Computational Social Systems, 6(6), 1386–1394. 10.1109/TCSS.2019.2918467

Xu, J. H. , Tian, Y. , Ma, T. H. , & Al-Nabhan, N. (2020 Aug 24). Intelligent manufacturing security model based on improved blockchain. Math Biosci. Eng., 17(5), 5633–5650. doi: 10.3934/mbe.2020303. PMID: 33120570.

Pop, C. *et al*. (Jan. 2018). Blockchain based decentralized management of demand response programs in smart energy grids. Sensors, 18(1), 162.

Hawlitschek, F. , Notheisen, B. , & Teubner, T. (May/Jun. 2018). The limits of trust-free systems: A literature review on blockchain technology and trust in the sharing economy. Electron. Commerce Res. Appl., 29, 50–63.

Fernández-Caramés, T. M. & Fraga-Lamas, P. (2018). A review on the use of blockchain for the Internet of Things. IEEE Access, 6, 32979–33001.

Shahbazi, Z. , & Byun, Y. C. (2021). Integration of blockchain, IoT, and machine learning for multistage quality control and enhancing security in smart manufacturing. Sensors, 21(4), 1–21. doi: 10.3390/s21041467

Bellavista, P. , Esposito, C. , Foschini, L. , Giannelli, C. , Mazzocca, N. , & Montanari, R. (2021 Jul 21). Interoperable Blockchains for Highly-Integrated Supply Chains in Collaborative Manufacturing. Sensors (Basel), 21(15), 4955. doi: 10.3390/s21154955. PMID: 34372191; PMCID: PMC8347888.

Leng, J. , Ye, S. , Zhou, M. , Zhao, J. L. , Liu, Q. , Guo, W. , Cao, W. , & Fu, L. (2021a). Blockchain-secured smart manufacturing in Industry 4.0: A survey. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 51(1), 237–252. doi: 10.1109/TSMC.2020.3040789

Ahram, T. , Sargolzaei, A. , Sargolzaei, S. , Daniels, J. , & Amaba, B. (June 2017). Blockchain technology innovations. In Proceedings of the IEEE Technology and Engineering Management Conference, Santa Clara, CA, USA. pp. 1–6.

Yuan, Y. , & Wang, F. (Sep. 2018). Blockchain and cryptocurrencies: Model, techniques, and applications. IEEE Trans. Syst., Man, Cybern., Syst., 48(9), 1421–1428.

Shahbazi, Z. , & Byun, Y. C. (2021 Feb 20). Integration of blockchain, iot and machine learning for multistage quality control and enhancing security in smart manufacturing. Sensors (Basel), 21(4), 1467. doi: 10.3390/s21041467. PMID: 33672464; PMCID: PMC7923442.

Wan, P. K. , Satybaldy, A. , Huang, L. , Holtskog, H. , & Nowostawski, M. (2020 Oct 28). Reducing alert fatigue by sharing low-level alerts with patients and enhancing collaborative decision making using blockchain technology: Scoping review and proposed framework (MedAlert). J Med. Internet Res., 22(10), e22013. doi: 10.2196/22013. PMID: 33112253; PMCID: PMC7657729.
Alkhader, W. , Salah, K. , Sleptchenko, A. , Jayaraman, R. , Yaqoob, I. , & Omar, M. (2021 Oct 5). Blockchain-based decentralized digital manufacturing and supply for COVID-19 medical devices and supplies. IEEE Access, 9, 137923–137940. doi: 10.1109/ACCESS.2021.3118085. PMID: 34812401; PMCID: PMC8545200.
Steinwandter V. , & Herwig C. (2019 Jul-Aug). Provable data integrity in the pharmaceutical industry based on version control systems and the blockchain. PDA J Pharm. Sci. Technol., 73(4), 373–390. doi: 10.5731/pdajpst.2018.009407. Epub 2019 Feb 15. PMID: 30770485.
Omidian, H. , & Omidi, Y. (2022 Apr). Blockchain in pharmaceutical life cycle management. Drug Discov. Today, 27(4), 935–938. doi: 10.1016/j.drudis.2022.01.018. Epub 2022 Feb 3. PMID: 35124248.
Pustišek, M. , Chen, M. , Kos, A. , & Kos, A. (2022 Jan 3). Decentralized machine autonomy for manufacturing servitization. Sensors (Basel), 22(1), 338. doi: 10.3390/s22010338. PMID: 35009881; PMCID: PMC8749772.
Krundyshev, V. , & Kalinin, M. (2020). Prevention of cyber attacks in smart manufacturing applying modern neural network methods. IOP Conference Series: Materials Science and Engineering, 940(1). doi: 10.1088/1757-899X/940/1/012011
Fernández, S. (2007). An application of recurrent neural networks to discriminative keyword spotting. Proceedings of the 17th International Conference on Artificial Neural Networks (Springer-Verlag). pp. 220–229.
Graves, A. , & Schmidhuber, J. (2009). Offline handwriting recognition with multidimensional recurrent neural networks. Advances in Neural Information Processing Systems, 545–552.
Montuschi, P. (2015). Spiking neural network architecture computer, in Computer, 48(i 10), 6, 10.1109/MC.2015.293.
Govindarajan, M. & Chandrasekaran, R. (2014). A hybrid multilayer perceptron neural network for direct marketing, International Journal of Knowledge-Based Organizations, 2(3), 63-73.. doi: 10.4018/ijkbo.2012070104
Gallant, S. (1990). Perceptron-based learning algorithms. IEEE Transactions on Neural Networks, 1(2), 179–191.
Ramya, R. , Anandanatarajan, R. , et al. (2012). Applications of fuzzy logic and artificial neural network for solving real world problem. IEEE-International Conference on Advances In Engineering, Science And Management (ICAESM – 2012). pp. 443–448.
Ghalia, M. , & Alouani, A. (1995). Artificial neural networks and fuzzy logic for system modeling and control: a comparative study. Proceedings of the 27th Southeastern Symposium on System Theory. pp. 258–262.
Bakir, T. , Boussaid, B. , et al. (2016). Artificial neural network based on wavelet transform and feature extraction for a wind turbine diagnosis system. 2016 14th International Conference on Control, Automation, Robotics and Vision (ICARCV). pp. 1–6.
Chao, L. , Tao, J. , et al. (2016). Long short term memory recurrent neural network based encoding method for emotion recognition in video. IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP).
Dai, J. , Liang, S. , et al. (2016) Long short-term memory recurrent neural network based segment features for music genre classification 10th International Symposium on Chinese Spoken Language Processing (ISCSLP). pp. 1–5.
Youmans, M. , Spainhour, C. , & Qiu, P. (2017) Long short-term memory recurrent neural networks for antibacterial peptide identification. IEEE International Conference on Bioinformatics and Biomedicine (BIBM). pp. 498–502.
Radford, A. , Metz, L. , & Chintala, S. (2015). Unsupervised representation learning with deep convolutional generative adversarial networks. arXiv preprint arXiv:1511.06434.
Yin, C. , Zhu, Y. , et al. (2018). An enhancing framework for botnet detection using generative adversarial networks Int. Conference on Artificial Intelligence and Big Data (ICAIBD). pp. 228–234.
Sze, V. , Chen, Y. , et al. (2017). Efficient processing of deep neural networks: A tutorial and survey. in Proc. of the IEEE, 105(12), 2295–2329.

Naik, D. , & Mammone, R. (1992). Meta-neural networks that learn by learning. International Joint Conference on Neural Networks Baltimore, USA.
Hans, A. , & Udluft, S. (2010). Ensembles of neural networks for robust reinforcement learning. 2010 9th Int. Conference on Machine Learning and Applications. pp. 401–406.
CIP008-5 Cyber Security – Incident Reporting and Response Planning. 2016 http://www.nerc.com/_layouts/PrintStandard.aspx?standardnumber=CIP-008-5.
USC Chapter 1, Subchapter XVI: Chemical Facility Anti-Terrorism Standards. 2014 http://uscode.house.gov/view.xhtml?path=/prelim@title6/chapter1/subchapter16&edition=prelim.
Line, M. , Tondel, I. , & Jaatun, M. (2014). Information security incident management: Planning for failure. 2014 Eighth International Conference on IT Security Incident Management IT Forensics (IMF). pp. 47–61. doi: 10.1109/IMF.2014.10
Spyridopoulos, T. , Tryfonas, T. , & May, J. (2013). Incident analysis amp; digital forensics in SCADA and industrial control systems. 8th IET International System Safety Conference incorporating the Cyber Security Conference 2013. pp. 1–6. doi: 10.1049/cp.2013.1720

Integration of Circular Supply Chain and Industry 4.0 to Enhance Smart Manufacturing Adoption

M. S. R. A. Hamid , N. R. Masrom , and N. A. B. Mazlan , The key factors of the industrial revolution 4.0 in the Malaysian smart manufacturing context, Int. J. Asian Bus. Inf. Manag., vol. 13, no. 2, pp. 1–19, 2022, 10.4018/IJABIM.20220701.oa6
P. Lengyel *et al*. , Development of the concept of circular supply chain management—A systematic review, Processes, vol. 9, no. 10, pp. 1–20, 2021, 10.3390/pr9101740
T. S. Deepu and V. Ravi , Supply chain digitalization: An integrated MCDM approach for inter-organizational information systems selection in an electronic supply chain, Int. J. Inf. Manag. Data Insights, vol. 1, no. 2, p. 100038, 2021, 10.1016/j.jjimei.2021.100038
D. Huybrechts , A. Derden , L. Van den Abeele , S. Vander Aa , and T. Smets , Best available techniques and the value chain perspective, J. Clean. Prod., vol. 174, pp. 847–856, 2018, 10.1016/j.jclepro.2017.10.346
J. Friederich , D. P. Francis , S. Lazarova-Molnar , and N. Mohamed , A framework for data-driven digital twins for smart manufacturing, Comput. Ind., vol. 136, p. 103586, 2022, 10.1016/j.compind.2021.103586
T. D. Mastos *et al* ., Introducing an application of an industry 4.0 solution for circular supply chain management, J. Clean. Prod., vol. 300, 2021, 10.1016/j.jclepro.2021.126886
J. Wang , Y. Ma , L. Zhang , R. X. Gao , and D. Wu , Deep learning for smart manufacturing: Methods and applications, J. Manuf. Syst., vol. 48, pp. 144–156, 2018, 10.1016/j.jmsy.2018.01.003
N. K. Dev , R. Shankar , R. Gupta , and J. Dong , Multi-criteria evaluation of real-time key performance indicators of supply chain with consideration of big data architecture, Comput. Ind. Eng., vol. 128, pp. 1076–1087, 2019, 10.1016/j.cie.2018.04.012
J. Reinhold , C. Koldewey , and R. Dumitrescu , Value creation framework and roles for smart services, Procedia CIRP, vol. 109, pp. 413–418, 2022, 10.1016/j.procir.2022.05.271
J. Valenzuela , M. Alfaro , G. Fuertes , M. Vargas , and C. Sáez-Navarrete , Reverse logistics models for the collection of plastic waste: A literature review, Waste Manag. Res., 39(9), pp.1116-1134, 2021, 10.1177/0734242X211003948
J. C. Serrano-Ruiz , J. Mula , and R. Poler , Smart manufacturing scheduling: A literature review, J. Manuf. Syst., vol. 61, no. September, pp. 265–287, 2021, 10.1016/j.jmsy.2021.09.011
J. C. Serrano-Ruiz , J. Mula , and R. Poler , Development of a multidimensional conceptual model for job shop smart manufacturing scheduling from the Industry 4. 0 perspective, J. Manuf. Syst., vol. 63, no. February, pp. 185–202, 2022, 10.1016/j.jmsy.2022.03.011
B. Elahi and S. A. Tokaldany , Application of Internet of Things-aided simulation and digital twin technology in smart manufacturing. INC, 2021.
S. Blömeke , J. Rickert , M. Mennenga , S. Thiede , T. S. Spengler , and C. Herrmann , Recycling 4.0 – Mapping smart manufacturing solutions to remanufacturing and recycling operations, Procedia CIRP, vol. 90, pp. 600–605, 2020, 10.1016/j.procir.2020.02.045

H. Gupta , A. Kumar , and P. Wasan , Industry 4.0, cleaner production and circular economy: An integrative framework for evaluating ethical and sustainable business performance of manufacturing organizations, J. Clean. Prod., vol. 295, p. 126253, 2021, 10.1016/j.jclepro.2021.126253

Y. Riahi , T. Saikouk , A. Gunasekaran , and I. Badraoui , Artificial intelligence applications in supply chain: A descriptive bibliometric analysis and future research directions, Expert Syst. Appl., vol. 173, no. November 2020, p. 114702, 2021, 10.1016/j.eswa.2021.114702

S. Luthra , M. Sharma , A. Kumar , S. Joshi , E. Collins , and S. Mangla , Overcoming barriers to cross-sector collaboration in circular supply chain management: A multi-method approach, Transp. Res. Part E Logist. Transp. Rev., vol. 157, no. May 2021, p. 102582, 2022, 10.1016/j.tre.2021.102582

S. Mittal , M. A. Khan , D. Romero , and T. Wuest , Building blocks for adopting smart manufacturing, Procedia Manuf., vol. 34, pp. 978–985, 2019, 10.1016/j.promfg.2019.06.098

S. Cisneros-Cabrera , G. Pishchulov , P. Sampaio , N. Mehandjiev , Z. Liu , and S. Kununka , An approach and decision support tool for forming Industry 4.0 supply chain collaborations, Comput. Ind., vol. 125, p. 103391, 2021, 10.1016/j.compind.2020.103391

E. Cesur , M. R. Cesur , Y. Kayikci , and S. K. Mangla , Optimal number of remanufacturing in a circular economy platform, Int. J. Logist. Res. Appl., pp. 1–17, 2020, 10.1080/13675567.2020.1825656

E. K. Zavadskas , J. Antucheviciene , and P. Chatterjee , Multiple-criteria decision-making (MCDM) techniques for business processes information management, Inf., vol. 10, no. 1, pp. 1–7, 2018, 10.3390/info10010004

B. M. Bringsken , I. Loureiro , C. Ribeiro , C. Vilarinho , and J. Carvalho , Community involvement towards a circular economy: A sociocultural assessment of projects and interventions to reduce undifferentiated waste, Eur. J. Sustain. Dev., vol. 7, no. 4, pp. 496–506, 2018, 10.14207/ejsd.2018.v7n4p496

T. Arauz , P. Chanfreut , and J. M. Maestre , Cyber-security in networked and distributed model predictive control, Annu. Rev. Control, vol. 53, no. October 2021, pp. 338–355, 2022, 10.1016/j.arcontrol.2021.10.005

I. Mezgár and J. Váncza , From ethics to standards – A path via responsible AI to cyber-physical production systems, Annu. Rev. Control, vol. 53, no. April, pp. 391–404, 2022, 10.1016/j.arcontrol.2022.04.002

S. Alonso-Muñoz , R. González-Sánchez , C. Siligardi , and F. E. García-Muiña , Building exploitation routines in the circular supply chain to obtain radical innovations, Resources, vol. 10, no. 3, pp. 1–18, 2021, 10.3390/resources10030022

S. Çetin , C. De Wolf , and N. Bocken , Circular digital built environment: An emerging framework, Sustain., vol. 13, no. 11, 2021, 10.3390/su13116348

M. V. Hernandez Marquina , M. A. Le Dain , P. Zwolinski , and I. Joly , Sustainable performance of circular supply chains: A literature review., Procedia CIRP, vol. 105, pp. 607–612, 2022, 10.1016/j.procir.2022.02.101

M. Despeisse *et al* ., Unlocking value for a circular economy through 3D printing: A research agenda, Technol. Forecast. Soc. Change, vol. 115, pp. 75–84, 2017, 10.1016/j.techfore.2016.09.021

C. Dalhammar , Industry attitudes towards ecodesign standards for improved resource efficiency, J. Clean. Prod., vol. 123, pp. 155–166, 2016, 10.1016/j.jclepro.2015.12.035

X. Zhang , Z. Li , Y. Wang , and W. Yan , An integrated multicriteria decision-making approach for collection modes selection in remanufacturing reverse logistics, Processes, vol. 9, no. 4, 2021, 10.3390/pr9040631

G. Yadav , S. Luthra , D. Huisingh , S. K. Mangla , B. E. Narkhede , and Y. Liu , Development of a lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies, J. Clean. Prod., vol. 245, p. 118726, 2020, 10.1016/j.jclepro.2019.118726

R. K. A. Bhalaji , S. Bathrinath , and S. Saravanasankar , A Fuzzy VIKOR method to analyze the risks in lean manufacturing implementation, Mater. Today Proc., vol. 45, no. xxxx, pp. 1294–1299, 2021, 10.1016/j.matpr.2020.05.123

G. Yadav , D. Seth , and T. N. Desai , Application of hybrid framework to facilitate lean six sigma implementation: A manufacturing company case experience, Prod. Plan. Control, vol. 29, no. 3, pp. 185–201, 2018, 10.1080/09537287.2017.1402134

M. V. C. Fagundes , B. Hellingrath , and F. G. M. Freires , Supplier selection risk: A new computer-based decision-making system with fuzzy extended AHP, Logistics, vol. 5, no. 1, p. 13, 2021, 10.3390/logistics5010013
G. Yadav , D. Seth , and T. N. Desai , Prioritising solutions for Lean Six Sigma adoption barriers through fuzzy AHP-modified TOPSIS framework, Int. J. Lean Six Sigma, vol. 9, no. 3, pp. 270–300, 2018, 10.1108/IJLSS-06-2016-0023
G. Yadav , S. K. Mangla , A. Bhattacharya , and S. Luthra , Exploring indicators of circular economy adoption framework through a hybrid decision support approach, J. Clean. Prod., vol. 277, p. 124186, 2020, 10.1016/j.jclepro.2020.124186
P. Gerli , J. Clement , G. Esposito , L. Mora , and N. Crutzen , The hidden power of emotions: How psychological factors influence skill development in smart technology adoption, Technol. Forecast. Soc. Change, vol. 180, no. April, p. 121721, 2022, 10.1016/j.techfore.2022.121721
S. Lahane , R. Kant , and R. Shankar , Circular supply chain management: A state-of-art review and future opportunities, J. Clean. Prod., vol. 258, p. 120859, 2020, 10.1016/j.jclepro.2020.120859
C. Garrido-Hidalgo , F. J. Ramirez , T. Olivares , and L. Roda-Sanchez , The adoption of internet of things in a circular supply chain framework for the recovery of WEEE: The case of Lithium-ion electric vehicle battery packs, Waste Manag., vol. 103, pp. 32–44, 2020, 10.1016/j.wasman.2019.09.045
J. A. C. Bokhorst , W. Knol , J. Slomp , and T. Bortolotti , International journal of production economics assessing to what extent smart manufacturing builds on lean principles, Int. J. Prod. Econ., vol. 253, no. September 2021, p. 108599, 2022, 10.1016/j.ijpe.2022.108599
A. S. Homrich , G. Galvão , L. G. Abadia , and M. M. Carvalho , The circular economy umbrella: Trends and gaps on integrating pathways, J. Clean. Prod., vol. 175, pp. 525–543, 2018, 10.1016/j.jclepro.2017.11.064

Artificial Intelligence with Additive Manufacturing

Napoleone, A. , Macchi, M. , Pozzetti, A. A review on the characteristics of cyber-physical systems for the future smart factories, J. Manuf. Syst., 54 (2020), 305–335.
Grabowska, S. Smart factories in the age of industry 4.0, Manag. Syst. Prod. Eng., 28 (2020), 90–96.
Kagermann, H. , Wahlster, W. , Helbig, J. Recommendations for Implementing the Strategic Initiative Industrie 4.0: Final Report of the Industrie 4.0 Working Group, Acatec–National Academy of Science and Engineering: Munich, Germany, (2011).
Tu, M. , Lim, M. , Yang, M. IoT-based production logistics and supply chain, Ind. Manag. Data Syst., 118 (2018), 96–125. [Google Scholar] [CrossRef][Green Version].
Khajavi, S. H. , Ituarte, I. F. , Jaribion, A. , An, J. , Kai, C. C. , Holmstrom, J. Impact of additive manufacturing on supply chain complexity. In Proceedings of the 53rd Hawaii International Conference on System, Maui, HI, USA, 7–10, January (2020).
Devi, A. , Mathiyazhagan, K. , Kumar, H. Additive manufacturing in supply chain management: A systematic review. In Advances in Manufacturing and Industrial Engineering. Lecture Notes in Mechanical Engineering, Springer: Singapore, (2021), pp. 455–464.
Gaddam, A. , Wilkin, T. , Angelova, M. , Gaddam, J. Detecting sensor faults, anomalies and outliers in the internet of things: A survey on the challenges and solution, Electronics, 9 (2020), 511, 10.3390/electronics9030511www.mdpi.com/journal/electronics
Savolainen, J. , Collan, M. How additive manufacturing technology changes business models? –Review of literature, Addit. Manuf., 32 (2020), 101070.
Huang, H. , Ma, N. , Chen, J. , Feng, Z. , Murakawa, H. Toward large-scale simulation of residual stress and distortion in wire and arc additive manufacturing, Addit. Manuf., 34 (C), (2020) 101248.
Liang, X. , Cheng, L. , Chen, Q. , Yang, Q. , To, A. C. , A modified method for estimating inherent strains from detailed process simulation for fast residual distortion prediction of single-walled structures fabricated by directed energy deposition, Addit. Manuf., 23 (2018) 471–486.
Jimenez, X. , Dong, W. , Paul, S. , Klecka, M. A. , To, A. C. Residual stress modeling with phase transformation for wire arc additive manufacturing of B91 steel, JOM, 72, (2020)

4178–4186.
Lee, Y. , Bandari, Y. , Nandwana, P. , Gibson, B. , Richardson, B. , Simunovic, S. Effect of interlayer cooling time, constraint and tool path strategy on deformation of large components made by laser metal deposition with wire, Appl. Sci., 9 (23) (2019), 5115.
Nycz, A. , Noakes, M. , Richardson, B. , Messing, A. , Post, B. , Paul, J. , Flamm, J. , Love, L. Challenges in making complex metal large-scale parts for additive manufacturing: A case study based on the additive manufacturing excavator, Proceedings of the 28th Annual International Solid Freeform Fabrication Symposium—An Additive Manufacturing Conference, (2017).
Song, X. , Feih, S. , Zhai, W. , Sun, C.-N. , Li, F. , Maiti, R. , Wei, J. , Yang, Y. , Oancea, V. , Brandt, L. R. Advances in additive manufacturing process simulation: Residual stresses and distortion predictions in complex metallic components, Mater. Des., 193 (2020), 108779.
Walker, D. , Residual stress measurement techniques, Adv. Mater. Process., 159 (8) (2001), 30–33.
Ueda, Y. , Fukuda, K. , Tanigawa, M. New measuring method of three dimensional residual stresses based on theory of inherent strain (welding mechanics, strength & design), Trans. JWRI, 8 (2) (1979), 249–256.
Deng, D. , Murakawa, H. , Liang, W. Numerical simulation of welding distortion in large structures, Comput. Methods Appl. Mech. Eng., 196 (45–48) (2007), 4613–4627.
Li, C. , Denlinger, E. R. , Gouge, M. F. , Irwin, J. E. , Michaleris, P. Numerical verification of an Octree mesh coarsening strategy for simulating additive manufacturing processes, Addit. Manuf., 30 (2019), 100903.
Denlinger, E. R. , Irwin, J. , Michaleris, P. Thermomechanical modeling of additive manufacturing large parts, J. Manuf. Sci. Eng., 136 (6) (2014).
Stockman, T. , Schneider, J. A. , Walker, B. , Carpenter, J. S. A 3d finite difference thermal model tailored for additive manufacturing, JOM, 71 (3) (2019) 1117–1126.
Ding, D. , Pan, Z. , Cuiuri, D. , Li, H. A practical path planning methodology for wire and arc additive manufacturing of thin-walled structures, Rob. Comput. Integer. Manuf., 34 (2015), 8–19.
Hu, X. , Nycz, A. , Lee, Y. , Shassere, B. , Simunovic, S. , Noakes, M. , Ren, Y. , Sun, X. Towards an integrated experimental and computational framework for large-scale metal additive manufacturing, Mater. Sci. Eng., A 761 (2019), 138057.
Rodrigues, T. A. , Duarte, V. , Miranda, R. , Santos, T. G. , Oliveira, J. Current status and perspectives on wire and arc additive manufacturing (WAAM), Materials, 12 (7) (2019), 1121.
Paul, A. , Mozaffar, M. , Yang, Z. , Liao, W.-K. , Choudhary, A. , Cao, J. , Agrawal, A. A real-time iterative machine learning approach for temperature profile prediction in additive manufacturing processes, In 2019 IEEE International Conference on Data Science and Advanced Analytics (DSAA), IEEE, (2019), pp. 541–550.
Tapia, G. , Khairallah, S. , Matthews, M. , King, W. E. , Elway, A. Gaussian process-based surrogate modeling framework for process planning in laser powder bed fusion additive manufacturing of 316L stainless steel, Int. J. Adv. Manuf. Technol., 94 (9–12) (2018), 3591–3603.
Pereira, T. , Kennedy, J. V. , Potgieter, J. A comparison of traditional manufacturing vs additive manufacturing, the best method for the job, Procedia Manuf., 30 (2019), 11–18.
Rojek, I. , Mikołajewski, D. , Kotlarz, P. , Macko, M. , Kopowski, J. Intelligent system supporting technological process planning for machining In MATEC Web of Conferences, vol. 357, p. 04001,EDP Sciences, 2022.
Grzesik, W. Hybrid machining processes. Definitions, generation rules and real industrial importance, Mechanik, 5–6 (2018), 338–342.
Abouna, G. M. Organ shortage crisis: Problems and possible solutions, Transplant. Proc., 40 (2008), 34–38.
Mandrycky, C. , Wang, Z. , Kim, K. , Kim, D. H. 3D bioprinting for engineering complex tissues, Biotechnol. Adv., 34 (2016), 422–434.
Khademhosseini, A. , Langer, R. , Borenstein, J. , Vacanti, J. P. Microscale technologies for tissue engineering and biology, Proc. Natl. Acad. Sci. USA, 103 (2006), 2480–2487.
Chen, X. B. . Extrusion Bioprinting of Scaffolds for Tissue Engineering. Springer Nature Switzerland AG: Cham, Switzerland, (2019).
Kozior, T. , Bochnia, J. , Gogolewski, D. , Zmarzły, P. , Rudnik, M. , Szot, W. , Szczygieł, P. , Musiałek, M. Analysis of metrological quality and mechanical properties of models

manufactured with photo-curing polyjet matrix technology for medical applications, Polymers, 14 (2022), 408.
Betancourt, N. , Chen, X. Review of extrusion-based multi-material bioprinting processes, Bioprinting, 25 (2022), e00189.
You, F. , Wu, X. , Kelly, M. , Chen, X. Bioprinting and in vitro characterization of alginate dialdehyde–Gelatin hydrogel bio-ink, Bio-Des. Manuf., 3 (2020), 48–59.
Delkash, Y. , Gouin, M. , Rimbeault, T. , Mohabatpour, F. , Papagerakis, P. , Maw, S. , Chen, X. Bioprinting and in vitro characterization of an eggwhite-based cell-laden patch for endothelialized tissue engineering applications, J. Funct. Biomater., 12 (2021), 45.
Sadeghianmaryan, A. , Naghieh, S. , Alizadeh Sardroud, H. , Yazdanpanah, Z. , Afzal Soltani, Y. , Sernaglia, J. , Chen, X. Extrusionbased printing of chitosan scaffolds and their in vitro characterization for cartilage tissue engineering, Int. J. Biol. Macromol., 164 (2020), 3179–3192.
Ning, L. , Zhu, N. , Smith, A. , Rajaram, A. , Hou, H. , Srinivasan, S. , Mohabatpour, F. , He, L. , McLnnes, A. , Serpooshan, V. , et al. Noninvasive three-dimensional in situ and in vivo characterization of bioprinted hydrogel scaffolds using the X-ray propagation based imaging technique, ACS Appl. Mater. Interfaces, 13 (2021), 25611–25623.
Naghieh, S. , Sarker, M. D. , Sharma, N. K. , Barhoumi, Z. , Chen, X. Printability of 3D printed hydrogel scaffolds: Influence of hydrogel composition and printing parameters, Appl. Sci., 10 (2020), 292.
Zimmerling, A. , Yazdanpanah, Z. , Cooper, D. M. L. , Johnston, J. D. , Chen, X. 3D printing PCL/nHA bone scaffolds: Exploring the influence of material synthesis techniques, Biomater. Res., 25 (2021), 3.
Suntornnond, R. , Tan, E. Y. S. , An, J. , Chua, C. K. A mathematical model on the resolution of extrusion bioprinting for the development of new bioinks, Materials, 9 (2016), 756.
Zhang, Z. , Jin, Y. , Yin, J. , Xu, C. , Xiong, R. , Christensen, K. , Ringeisen, B. R. , Chrisey, D. B. , Huang, Y. Evaluation of bioink printability for bioprinting applications, Appl. Phys. Rev., 5 (2018), 041304.
Müller, M. , Becher, J. , Schnabelrauch, M. , Zenobi-Wong, M. Nanostructured pluronic hydrogels as bioinks for 3D bioprinting, Biofabrication, 7 (2015), 035006. [CrossRef].
Kyle, S. , Jessop, Z. M. , Al-Sabah, A. , Whitaker, I. S. ‘Printability’ of candidate biomaterials for extrusion based 3D printing: State-of-the-art, Adv. Healthc. Mater., 6 (2017), 1700264.
Fathizadan, S. Real-time monitoring and optimal control for smart additive manufacturing (Doctoral dissertation, Arizona State University), (2022).
Rani, R. M. , Kavitha, R. , Deeptha, R. Analysis of human activities in smart home using abnormal activity recognition algorithm (AAR) and visualization techniques, International Journal of Early Childhood Special Education, vol. 14, issue 5, pp. 749-761, Turkey, 2020.
Nycz, A. , Lee, Y. , Noakes, M. , Ankit, D. , Masuo, C. , Simunovic, S. , Bunn, J. et al. Effective residual stress prediction validated with neutron diffraction method for metal large-scale additive manufacturing, Materials & Design, 205 (2021), 109751.
Wang, C. , Li, S. , Zeng, D. , Zhu, X. An Artificial-intelligence/statistics solution to quantify material distortion for thermal compensation in additive manufacturing, *arXiv preprint arXiv:2005.09084* (2020).
Rojek, I. , Mikołajewski, D. , Kotlarz, P. , Macko, M. , Kopowski, J. Intelligent system supporting technological process planning for machining and 3D printing, Bulletin of the Polish Academy of Sciences. Technical Sciences, 69(2), pp. 1–8, (2021).
Paraskevoudis, K. , Karayannis, P. , Koumoulos, E. P. Real-time 3D printing remote defect detection (stringing) with computer vision and artificial intelligence, Processes, 8(11) (2020), 1464.
Palanisamy, P. , Mohan, R. E. , Semwal, A. , Melivin, L. M. J. , Félix Gómez, B. , Balakrishnan, S. , Elangovan, K. , Ramalingam, B. , Ng Terntzer, D. Drain structural defect detection and mapping using AI-enabled reconfigurable robot raptor and IoRT framework, Sensors, 21(21) (2021), 7287.
Jo, Y. , Hwang, D. G. , Kim, M. , Yong, U. , Jang, J. Bioprinting-assisted tissue assembly to generate organ substitutes at scale, Trends in Biotechnology, vol. 41, issue 1, pp. 93–105, (2022).
Malekpour, A. , Chen, X. Printability and cell viability in extrusion-based bioprinting from experimental, computational, and machine learning views, Journal of Functional Biomaterials, 13(2) (2022), 40.

Shin, J. , Lee, Y. , Li, Z. , Hu, J. , Park, S. S. , Kim, K. Optimized 3D bioprinting technology based on machine learning: A review of recent trends and advances, Micromachines, 13(3) (2022), 363.

Mao, A. S. , Mooney, D. J. Regenerative medicine: Current therapies and future directions, Proc. Natl. Acad. Sci. USA, 112 (2015), 14452.

Skardal, A. , Shupe, T. , Atala, A. Body-on-a-chip: Regenerative medicine for personalized medicine, Atala, A., Lanza, R., Mikos, T., & Nerem, R. (Eds.), Principles of regenerative medicine. Academic press, (2019), 769–786, 10.1016/B978-0-12-809880-6.00044-8.

Risse, G. B. , Warner, J. H. Reconstructing clinical activities: Patient records in medical history, Soc. Hist. Med., 5 (1992), 183–205.

Hamburg, M. A. , Collins, F. S. The path to personalized medicine, N. Engl. J. Med., 363 (2010), 301–304.

Jovic, T. H. , Combellack, E. J. , Jessop, Z. M. , Whitaker, I. S. 3D bioprinting and the future of surgery, Front. Surg., vol. 7, article 609836, (2020).

Mironov, V. , Kasyanov, V. , Markwald, R. R. Organ printing: From bioprinter to organ biofabrication line, Curr. Opin. Biotechnol., 22 (2011), 667–673.

Ramesh, S. , Harrysson, O. L. A. , Rao, P. K. , Tamayol, A. , Cormier, D. R. , Zhang, Y. , Rivero, I. V. Extrusion bioprinting: Recent progress, challenges, and future opportunities, Bioprinting, 21 (2021), e00116.

Li, X. , Liu, B. , Pei, B. , Chen, J. , Zhou, D. , Peng, J. , Zhang, X. , Jia, W. , Xu, T. Inkjet Bioprinting of biomaterials, Chem. Rev., 120 (2020), 10793–10833.

Wang, Z. , Abdulla, R. , Parker, B. , Samanipour, R. , Ghosh, S. , Kim, K. A simple and high-resolution stereolithography-based 3D bioprinting system using visible light crosslinkable bioinks, Biofabrication, 7 (2015), 045009.

Nair, K. , Gandhi, M. , Khalil, S. , Yan, K. C. , Marcolongo, M. , Barbee, K. , Sun, W. Characterization of cell viability during bioprinting processes, Biotechnol. J., 4 (2009), 1168–1177.

Delli, U. , Chang, S. Automated process monitoring in 3D printing using supervised machine learning, Procedia Manuf., 26 (2018), 865–870.

Ji, C. , Mandania, R. , Liu, J. , Liret, A. , Kern, M. Incorporating risk in field services operational planning process. In International Conference on Innovative Techniques and Applications of Artificial Intelligence, Springer: Cham, Switzerland; Cambridge, UK, (2018), Volume 11311 LNAI, ISBN 9783030041908.

Goh, G. D. , Sing, S. L. , Yeong, W. Y. A review on machine learning in 3D printing: Applications, potential, and challenges, Artif. Intell. Rev., 54 (2021), 63–94.

Menon, A. , Póczos, B. , Feinberg, A. W. , Washburn, N. R. Optimization of silicone 3D printing with hierarchical machine learning, 3D Print. Addit. Manuf., 6 (2019), 181–189.

https://patentscope.wipo.int/search/en/result.jsf?_vid=P20-L6Q3E6–52733 – Accessed 12 August 2022.

Robotic Additive Manufacturing Vision towards Smart Manufacturing and Envisage the Trend with Patent Landscape

C. K. Chua , K. F. Leong , 3D Printing and Additive Manufacturing: Principles and Applications, 5th ed., SG: World Scientific, (2017).

D. Bengs , M. Z. Cordero , Technobothnia has a new robotic additive manufacturing environment (2021). Vaasa Insider 30 December 2021.

Z. Hu , L. Hua , X. Qin , M. Ni , Z. Liu , C. Liang , Region-based path planning method with all horizontal welding position for robotic curved layer wire and arc additive manufacturing, Robotics and Computer-Integrated Manufacturing 74 (2022), 102286.

J. C. S. McCaw et al. Curved-layered additive manufacturing of nonplanar, parametric lattice structures, Mater. Des., vol. 160, pp. 949–963, (2018).

Z.-Y. Liao , J.-R. Li , H.-L. Xie , Q.-H. Wang , X.-F. Zhou , Region-based toolpath generation for robotic milling of freeform surfaces with stiffness optimization, Robotics, and Computer-Integrated Manufacturing 64 (2020), 101953.

T. Lehmann , D. Rose , E. Ranjbar , M. Ghasri-Khouzani , M. Tavakoli , H. Henein , T. Wolfe & A. J. Qureshi . Large-scale metal additive manufacturing: A holistic review of the state of the art and challenges, International Materials Reviews 67 (4) (2022), 410–459. 10.1080/09506608.2021.1971427

P. M. Bhatt , R. K. Malhan , A. V. Shembekar , Y. J. Yoon , S. K. Gupta , Expanding capabilities of additive manufacturing through use of robotics technologies: A survey, Additive Manufacturing 31 (2020), 100933.

N. Hack , W. Lauer , S. Langenberg , F. Gramazio , M. Kohler , Overcoming 845 repetition: Robotic fabrication processes at a large scale, International Journal of Architectural Computing 11 (3) (2013), 285–299.

B. G. de Soto , I. Agust-Juan , J. Hunhevicz , S. Joss , K. Graser , G. Habert , B. T. Adey , Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall, Automation in Construction 850 (92) (2018), 297–311.

T. Lehmann , A. Jain , Y. Jain , H. Stainer , T. Wolfe , H. Henein , A. J. Qureshi , Concurrent geometry- and material-based process identification and optimization for robotic CMT-based wire arc additive manufacturing, Materials & Design 194 (2020), 108841.

J. Duro-Royo , L. Mogas-Soldevila , N. Oxman , Flow-based Fabrication: An integrated computational workflow for design and digital additive manufacturing of multifunctional heterogeneously structured objects, Computer-Aided Design 69 (2015), 143–154.

Y. J. Yoon , M. Yon , S. E. Jung , S. K. Gupta , Development of threenozzle extrusion system for conformal multi-resolution 3D printing with a robotic manipulator, in ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers, vol. 59179, p. V001T02A024, Anaheim, California, (2019).

I. E. Yigit , S. A. Khan , I. L. Lazoglu , Robotic additive manufacturing of tooling for composite structures, in The 18th International Conference on Machine Design and Production (UMTIK), Eskişehir, Turkey, (July 2018).

A. V. Shembekar , Y. J. Yoon , A. Kanyuck , S. K. Gupta , Generating robot trajectories for conformal 3D printing using non-planar layers, Journal of Computing and Information Science in Engineering, vol. 19, issue 3, pp. 031011 (2019). 10.1115/1.4043013

L. B. L. Huo , The joint-limits and singularity avoidance in robotic welding, Industrial Robot: The International Journal of Robotics Research and Application 35 (5) (2008), 456–464.

H. Chen , T. Fuhlbrigge , X. Li , Automated industrial robot path planning for spray painting process: A review, in 2008 IEEE International Conference on Automation Science and Engineering, (August 2008), pp. 522–527.

A. M. Kabir , K. N. Kaipa , J. Marvel , S. K. Gupta , Automated planning for robotic cleaning using multiple setups and oscillatory tool motions, IEEE Transactions on Automation Science and Engineering 14 (3) (July 2017), 1364–1377.

A. M. Kabir , B. C. Shah , S. K. Gupta , Trajectory planning for manipulators operating in confined workspaces, in 2018 IEEE International Conference on Automation Science and Engineering (CASE), Munich, Germany, (August 2018).

D. Ding , Z. Pan , D. Cuiuri , H. Li , N. Larkin , Adaptive path planning for wire-feed additive manufacturing using medial axis transformation, Journal of Cleaner Production 133 (2016), 942–952.

G. Zhao , G. Ma , J. Feng , W. Xiao , Nonplanar slicing and path generation methods for robotic additive manufacturing, The International Journal of Advanced Manufacturing Technology 96 (9–12) (2018), 3149–3159. 10.1007/s00170-018-1772-9

P. M. Bhatt , Process Planning for Robotic Additive Manufacturing, Ph.D Thesis, (2022), https://www.proquest.com/openview/1a58998e9b5ca1e430ff59258bda2333/1?pq-origsite=gscholar&cbl=18750&diss=y

T. S. Tamir , G. Xiong , X. Dong et al. , Design and optimization of a control framework for robot-assisted additive manufacturing based on the stewart platform, Int. J. Control Autom. Syst. 20 (2022), 968–982. 10.1007/s12555-021-0058-4

G. Ma , G. Zhao , Z. Li et al. , Optimization strategies for robotic additive and subtractive manufacturing of large and high thin-walled aluminum structures, Int J Adv Manuf Technol 101 (2019), 1275–1292. 10.1007/s00170-018-3009-3

D. Ding , Z. Pan , D. Cuiuri , H. Li , A multi-bead overlapping model for robotic wire and arc additive manufacturing (WAAM). Robot Comput Integr Manuf 31 (2015), 101–110.

Y. Li , Y. Sun , Q. Han , G. Zhang , I. Horvath , Enhanced beads' overlapping model for wire and arc additive manufacturing of multi-layer multi-bead metallic parts, J Mater Process Technol 252 (2018), 838–848.

Y. Chen , Y. He , H. Chen , H. Zhang , S. Chen , Effect of weave frequency and amplitude on temperature field in weaving welding process. Int J Adv Manuf Technol 75 (5–8) (2014), 803–813.

A. Yaseer , H. Chen , Machine learning based layer roughness modeling in robotic additive manufacturing, Journal of Manufacturing Processes 70 (2021), 543–552.

Chen, H. , A. Yaseer , Y. Zhang , Top Surface Roughness Modeling for Robotic Wire Arc Additive Manufacturing, Journal of Manufacturing and Materials Processing 6 (2) (2022), 39. 10.3390/jmmp6020039

D. Ding , C. Shen , Z. Pan , D. Cuiuri , H. Li , N. Larkin , S. van Duin , Towards an automated robotic arc-welding-based additive manufacturing system from CAD to finished part, Computer-Aided Design 73 (2016), 66–75. 10.1016/j.cad.2015.12.003

B. Fabric , T. Schork , A. Menges Autonomous robotic additive manufacturing through distributed modelfree deep reinforcement learning in computational design environments. Constr Robot 6 (2022), 15–37. 10.1007/s41693-022-00069-0

S. Amarjyoti Deep reinforcement learning for robotic manipulation—The state of the art, (2017). http://arxiv.org/pdf/1701.08878v1

G. D. Goh , S. L. Sing , W. Y. Yeong , A review on machine learning in 3D printing: applications, potential, and challenges. Artif Intell Rev 54 (1) (2021), 63–94. 10.1007/s10462-020-09876-9

Z. Li , Z. Zhang , J. Shi , D. Wu Prediction of surface roughness in extrusion-based additive manufacturing with machine learning. Robot Comput Integr Manuf 57 (2019), 488–495.

A. Koeppe , C. A. Hernandez Padilla , M. Voshage , J. H. Schleifenbaum , B. Markert , Efficient numerical modeling of 3D-printed lattice-cell structures using neural networks, Manuf Lett 15 (2018), 147–150.

G. Williams , N. A. Meisel , T. W. Simpson , C. McComb , Design repository effectiveness for 3D convolutional neural networks: Application to additive manufacturing, J Mech Des 141 (11) (2019), e4044199.

X. Li , X. Jia , Q. Yang , J. Lee (2020). Quality analysis in metal additive manufacturing with deep learning. Journal of Intell Manuf, 31, 2003–2017 (2020).

O. Davtalab , A. Kazemian , X. Yuan et al. , Automated inspection in robotic additive manufacturing using deep learning for layer deformation detection. Journal of Intell Manuf 33 (2022), 771–784. 10.1007/s10845-020-01684-w

H. Lin , B. Li , Automated defect inspection of LED chip using deep convolutional neural network. Journal of Intell Manuf 30 (2019), 2525–2534.

K. Castelli , A. M. A. Zaki , A. Y. Balakrishnappa , M. Carnevale , H. Giberti , A path planning method for robotic additive manufacturing, in 2021 3rd International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), (2021), pp. 1–5. 10.1109/HORA52670.2021.9461380

S.-H. Suh , S. K. Kang , D.-H. Chung , I. Stroud , Theory and Design of CNC Systems, London: Springer, (2008).

F. M. Ribeiro , J. N. Pires , A. S. Azar , Implementation of a robot control architecture for additive manufacturing applications, Industrial Robot 46 (1) (2019), 73–82.

Y. Ding , R. Dwivedi , R. Kovacevic , Process planning for 8-axis robotized laser-based direct metal deposition system: A case on building revolved part, Robot Comput Integr Manuf 44 (2017), 67–76. 10.1016/j.rcim.2016.08.008

I. E. Yigit , I. Lazoglu Spherical slicing method and its application on robotic additive manufacturing. Prog Addit Manuf 5 (2020), 387–394. 10.1007/s40964-020-00135-5

https://patentscope.wipo.int/search/en/result.jsf?_vid=P12-L6WFLZ-18738. Accessed on 13 August 2021.

Smart Materials for Smart Manufacturing

Vladimir Pokropivny , Rynno Lohmus , Irina Hussainova , Alex Pokropivny , and Sergey Vlassov . Introduction to nanomaterials and nanotechnology, volume 1. Tartu University Press Ukraine, 2007.

Ibrahim Nazem Qader , Kök Mediha , Fethi Dagdelen , and Yıldırım Ay-Dogdu . A review of smart materials: Researches and applications. El-Cezeri, 6(3):755–788, 2019.

Gianni Ciofani . Smart nanoparticles for biomedicine. Elsevier, 2018.

Igor Galaev and Bo Mattiasson . Smart polymers: Applications in biotechnology and biomedicine. CRC Press, 2007.

Jim Davis , Thomas Edgar , Robert Graybill , Prakashan Korambath , Brian Schott , Denise Swink , Jianwu Wang , and Jim Wetzel . Smart manufacturing. Annual Review of Chemical and Biomolecular Engineering, 6:141–160, 2015.

Andrew Kusiak . Smart manufacturing. International Journal of Production Re-search, 56(1–2):508–517, 2018.

T Tadaki , K Otsuka , and K Shimizu . Shape memory alloys. Annual Review of Materials Science, 18(1):25–45, 1988.

L McDonald Schetky . Shape-memory alloys. Scientific American, 241(5):74–83, 1979.

Andreas Lendlein and Steffen Kelch . Shape-memory polymers. Angewandte Chemie International Edition, 41(12):2034–2057, 2002.

Marc Behl and Andreas Lendlein . Shape-memory polymers. Materials Today, 10(4):20–28, 2007.

Yasubumi Furuya . Design and material evaluation of shape memory composites. Journal of Intelligent Material Systems and Structures, 7(3):321–330, 1996.

CC Wang , WM Huang , Z Ding , Y Zhao , and H Purnawali . Cooling- /water-responsive shape memory hybrids. Composites Science and Technology, 72(10):1178–1182, 2012.

Li Sun , Wei Min Huang , Zhi Ding , Y Zhao , Chang Chun Wang , Hendra Pur-Nawali , and Cheng Tang . Stimulus-responsive shape memory materials: a review. Materials & Design, 33:577–640, 2012.

D Damjanovic and RE Newnham . Electrostrictive and piezoelectric materials for actuator applications. Journal of Intelligent Material Systems and Structures, 3(2):190–208, 1992.

Kui Chen , Jian Ma , Juan Wu , Xiaoyi Wang , Feng Miao , Yi Huang , Caiyun Shi , Wenjuan Wu , and Bo Wu . Improve piezoelectricity in batio3-based ceramics with large electrostriction coefficient. Journal of Materials Science: Materials in Electronics, 31(15):12292–12300, 2020.

Steffen Gloeckner , Rolf Goering , Bernt Goetz , and Andreas Rose . Piezoelectrically driven micro-optical fiber switches. Optical Engineering, 37(4):1229–1234, 1998.

P Vinay , SS Venkata , M Hemanth , and A Saiteja . Design and simulation of mems based accelerometer for crash detection and air bags deployment in automobiles. International Journal of Mechanical Engineering and Technology, 8(4):424–434, 2017.

Youliang Cheng , Xiaoqiang Zhang , Changqing Fang , Jing Chen , and Zhen Wang . Discoloration mechanism, structures and recent applications of thermochromic materials via different methods: A review. Journal of Materials Science & Technology, 34(12):2225–2234, 2018.

Xiaojie Wang and Faramarz Gordaninejad . Magnetorheological materials and their applications. Intelligent materials, pages 339–385, 2008.

Mark R Jolly , J David Carlson , and Beth C Munoz . A model of the behaviour of magnetorheological materials. Smart Materials and Structures, 5(5):607, 1996.

Martin D Hager , Peter Greil , Christoph Leyens , Sybrand van der Zwaag , and Ulrich S Schubert . Self-healing materials. Advanced Materials, 22(47):5424–5430, 2010.

Mitsuhiro Ebara , Yohei Kotsuchibashi , Koichiro Uto , Takao Aoyagi , Young-Jin Kim , Ravin Narain , Naokazu Idota , and John M Hoffman . Smart hydrogels. In Smart biomaterials, pages 9–65. Springer, 2014.

Mutsumi Yoshida and Joerg Lahann . Smart nanomaterials. Acs Nano, 2(6):1101–1107, 2008.

Narender Ranga , Ekta Poonia , Shivani Jakhar , Ashok K Sharma , Atul Kumar , Sunita Devi , and Surender Duhan . Enhanced antimicrobial properties of bioactive glass using strontium and silver oxide nanocomposites. Journal of Asian Ceramic Societies, 7(1):75–81, 2019.

Allan S Hoffman , Patrick S Stayton , Volga Bulmus , Guohua Chen , Jingping Chen , Chuck Cheung , Ashutosh Chilkoti , Zhongli Ding , Liangchang Dong , Robin Fong , et al. Really smart

bioconjugates of smart polymers and receptor proteins. Journal of Biomedical Materials Research, 52(4):577–586, 2000.
Shukufe Amukarimi , Seeram Ramakrishna , and Masoud Mozafari . Smart biomaterials—A proposed definition and overview of the field. Current Opinion in Biomedical Engineering, 19:100311, 2021.
Rudolf Hufenus , Yurong Yan , Martin Dauner , Donggang Yao , and Takeshi Kikutani . Bicomponent fibers. Hu, Jinlian, Bipin Kumar, and Jing Lu (Eds), Handbook of fibrous materials, Wiley, pages 281–313, 2020.
CC Chu and LE Lecaroz . Design and in vitro testing of newly made bicomponent knitted fabrics for vascular surgery. In: Gebelein, C.G. (eds) Advances in Biomedical Polymers, pages 185–213. Springer, 1987.
Minoo Naebe and Kamyar Shirvanimoghaddam . Functionally graded materials: A review of fabrication and properties. Applied Materials Today, 5:223–245, 2016.
Rasheedat M Mahamood , Esther T Akinlabi , Mukul Shukla , and Sisa L Pityana . Functionally graded material: An overview, In Proceedings of the World Congress on Engineering, vol. 3, London, UK. 2012.
María Rosa Aguilar and Julio San Román . Smart polymers and their applications. Woodhead Publishing, 2019.
Atul Kumar , Narender Ranga , Surender Duhan , and Rajesh Thakur . In vitro study of aripiprazole loading and releasing efficiency of sba-16. Journal of Porous Materials, 27(5):1431–1437, 2020.
Narender Ranga , Suman Gahlyan , and Surender Duhan . Antibacterial efficiency of zn, mg and sr doped bioactive glass for bone tissue engineering. Journal of Nanoscience and Nanotechnology, 20(4):2465–2472, 2020.
Atul Kumar , Sunita Devi , Satish Khasa , and Surender Duhan . Biosurfactant as antibiofilm agent. In:Inamuddin, Charles Oluwaseun Adetunji, and Abdullah M. Asir (Eds) Green sustainable process for chemical and environmental engineering and science, pages 515–527. Elsevier, 2022.
RE Newnham , QC Xu , S Kumar , and LE Cross . Smart ceramics. Ferroelectrics, 102(1):259–266, 1990.
Ajay Kumar Mishra . Smart ceramics: Preparation, properties, and applications. CRC Press, 2018.
J Gopi Krishna and JR Thirumal . Application of smart materials in smart structures., International Journal of Innovative Research in Science Engineering and Technology, 4(7), 2015.
Vijay K Tomer and Surender Duhan . Ordered mesoporous ag-doped tio 2/sno 2 nanocomposite based highly sensitive and selective voc sensors. Journal of Materials Chemistry A, 4(3):1033–1043, 2016.
Georges Akhras . Smart materials and smart systems for the future. Canadian Military Journal, 1(3):25–31, 2000.
R Davidson . Smart composites: Where are they going? Materials & Design, 13(2):87–91, 1992.

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Singh, N. , & Sharma, U. C. (2014). Introduction to nano-biomaterials In: Navani, N. K. , & Singh S. (eds.), Nanotechnology, Vol. 11, pp. 1–12 Biomaterials, Texas, Studium Press.
Wang, M. (2004). Bioactive materials and processing, In: Shi, D. (ed.), Biomaterials and Tissue Engineering, pp. 1–82, Springer-Verlag, Berlin Heidelberg, Germany.
Kowalski, P. , & Bhattacharya, C. (2018). Smart biomaterials: Recent advances and future directions, Langer R. ACS Biomaterials Science and Engineering, 4(11), 3809–3817.
Hulbert, S. F. et al. (1987). Ceramics in clinical applications: Past, present and future, In: Vincezini, P. (ed.), High Tech Ceramics, pp. 189–213, Elsevier, Amsterdam, Netherlands.
Ratner, B. D. et al. (2004). Biomaterial Science: An Introduction to Materials in Medicine, Academic Press, San Diego, US.
Kondoyanni, M. , Loukatos, D. , Maraveas, C. , Drosos, C. , & Arvanitis, K. G. (2022). Bio-Inspired robots and structures toward fostering the modernization of agriculture. Biomimetics

(Basel, Switzerland), 7(2), 69. 10.3390/biomimetics7020069
Zhang, X. (2013). Biological effects and risks of nano-bioceramics. (www.cityu.edu.hk). Retrieved on April 12, 2013.
Alshabanah, L. , & Hagar, M. (2021). Hassanin, Hybrid nanofibrous membranes as a promising functional layer for personal protection equipment: Manufacturing and antiviral/antibacterial assessments. A Polymers, 13(11), pp. 1776.
Zhang, H. , Feng, M. , Fang, Y. , Wu, Y. , Liu, Y. , Zhao, Y. , & Xu, J. (2022). Recent advancements in encapsulation of chitosan-based enzymes and their applications in food industry. Critical Reviews in Food Science and Nutrition, 1–19. Advance online publication. 10.1080/10408398.2022.2086851
Yamato, M. , Konno, C. , Utsumi, M. , Kikuchi, A. , & Okano, T. (2002). Thermally responsive polymer-grafted surfaces facilitate patterned cell seeding and co-culture. Biomaterials, 23, 561–567.
Cao, Y. , Ibarra, C. , & Vacanti, C. (2006). Preparation and use of thermoresponsive polymers. In: Morgan, J. R. , Yarmush, M. L. , (eds.), Tissue Engineering: Methods and Protocols, pp. 75–84, Humana Press, New York. ISBN 978-1-59259-602-7.
Koss, K. M. , & Unsworth, L. D. (2016). Neural tissue engineering: Bioresponsive nanoscaffolds using engineered self-assembling peptides. Acta Biomater., 44, 2–15.
Zhao, X. , Kim, J. , Cezar, C. A. , Huebsch, N. , Lee, K. , & Bouhadir, K. (2011). Active scaffolds for on-demand drug and cell delivery. Proc. Natl. Acad. Sci. USA, 108, 67–72.
Kyle, S. , Felton, S. , McPherson, M. J. , Aggeli, A. , & Ingham, E. (2012). Rational molecular design of complementary self-assembling peptide hydrogels. Adv. Healthc. Mater., 1, 640–645.
Cao, Z. , Bian, Q. , Chen, Y. , Liang, F. , & Wang, G. (2017). Light-responsive Janus-particle-based coatings for cell capture and release. ACS Macro Lett., 6, 1124–1128.
Khan, F. , Tare, R. S. , Oreffo, R. O. C. , & Bradley, M. (2009). Versatile biocompatible polymer hydrogels: Scaffolds for cell growth. Angew. Chem. Int. Ed., 48(5), 978–982.
Williams, D. (1990). An introduction to medical and dental materials. In: Williams, D. (ed.), Concise Encyclopedia of Medical and Dental Materials, pp. Xvii–xx, Pergamon Press and MIT Press, England.
Saenz, A. , Brostow, W. , & Rivera-Muñoz, E. (1999). Ceramic biomaterials: An introductory overview. Journal of Materials Education, 21, 297–306.
Tien, N. D. , Lyngstadaas, S. P. , Mano, J. F. , Blaker, J. J. , & Haugen, H. J. (2021). Recent developments in chitosan-based micro/nanofibers for sustainable food packaging, smart textiles, cosmeceuticals, and biomedical applications. Molecules (Basel, Switzerland), 26(9), 2683. 10.3390/molecules26092683.
Akhila, V. , & Badwaik, L. S. (2022 April 1). Recent advancement in improvement of properties of polysaccharides and proteins based packaging film with added nanoparticles: A review. Int J Biol. Macromol., 203, 515–525. 10.1016/j.ijbiomac.2022.01.181. Epub 2022 Feb 2. PMID: 35122798.
Luo, M. , Zhang, X. , Wu, J. , & Zhao J. (2021 August 15). Modifications of polysaccharide-based biomaterials under structure-property relationship for biomedical applications. Carbohydrate Polym., 266, 118097. 10.1016/j.carbpol.2021.118097. Epub 2021 Apr 24. PMID: 34044964.
Benwood, C. , & Chrenek, J. (2021). Natural biomaterials and their use as bioinks for printing tissues, Willerth. Source-Bioengineering, 8(2), p. 27.
Daly, A. C. , Critchley, S. E. , Rencsok, E. M. , & Kelly, D. J. (2016). A comparison of different bioinks for 3D bioprinting of fibrocartilage and hyaline cartilage. Biofabrication, 8, 045002.
Janarthanan, G. , Tran, H. N. , Cha, E. , Lee, C. , Das, D. , & Noh, I. (2020). 3D printable and injectable lactoferrin-loaded carboxymethyl cellulose-glycol chitosan hydrogels for tissue engineering applications. Mater. Sci. Eng. C, 113, 111008.
Manickam, P. , Mariappan, S. A. , Murugesan, S. M. , Hansda, S. , Kaushik, A. , Shinde, R. , & Thipperudraswamy, S. P. . (2022). Artificial Intelligence (AI) and Internet of Medical Things (IoMT) assisted biomedical systems for intelligent healthcare. Biosensors, 12(8), 562. 10.3390/bios12080562
Salata, O. (2004). Applications of nanoparticles in biology and medicine. J Nanobiotechnol., 2, 3. 10.1186/1477-3155-2-3
Bhullar, S. , Bhullar, S. , & Ramkrishna, S. (2015). Smart Biomaterials – A Review, Rev. Adv. Mater. Sci, 40(3), 303–314.

Park, J. , & Lakes, R. S. (2007). Hard tissue replacement – II: Joints and teeth, In: Biomaterials: An Introduction, 395–458, Springer, New York.
Cheshire, N. J. W. , Wolfe, M. S. , Noone, M. A. , Davies, L. , & Drummond, M. (1992). The economics of femorocrural reconstruction for critical leg ischemia with and without autologous vein, Jounral Vasc. Surg., 15, 167–175.
Chlupáč, J. , Filová, E. , & Bačáková, L. (2009). Blood vessel replacement: 50 years of development and tissue engineering paradigms in vascular surgery. Physiol. Res., 58 (Suppl 2), S119–S140. 10.33549/physiolres.931918. PMID: 20131930.
Ali, M. N. , Busfield, J. J. C. , & Rehman, I. U. (2014). Auxetic oesophageal stents: Structure and mechanical properties. J Mater. Sci.: Mater. Med., 25, 527–553. 10.1007/s10856-013-5067-2
Caddock, B. D. , & Evans, K. E. (1995 Sep). Negative Poisson ratios and strain-dependent mechanical properties in arterial prostheses. Biomaterials, 16(14), 1109–1115. 10.1016/0142-9612(95)98908-w. PMID: 8519933.
Caddock, B. D. , & Evans, K. E. (1989). Microporous materials with negative Poisson's ratios. I. Microstructure and mechanical properties. Journal of Physics D: Applied Physics, 22, p. 1877. 10.1088/0022-3727/22/12/012
Chan, N. , & Evans, K. E. (1998). Indentation resilience of conventional and auxetic foams, J Cell. Plast., 34, 231–260.
Swanson, S. A. V. (1977). The scientific basis of joint replacement. In: S. A. V. Swanson & M. A. R. Freeman , (eds.), Pitman Medical Publishers, Turnbridge Wells, p. 130.
Kim, K. , & Sung, C. (2021). Computational and histological analyses for investigating mechanical interaction of thermally drawn fiber implants with brain tissue. Park Micromachines, 12(4), p. 394.
Abdelaal, A. M. , & Darwish, M. H. (2012). Analysis, fabrication and a biomedical application of auxetic cellular structure. International Journal of Engineering and Innovative Technology (IJEIT), 2, 218–223.
Saddow S. E. (2022). Silicon carbide technology for advanced human healthcare applications. Micromachines, 13(3), 346. 10.3390/mi13030346.
Stretching the Boundaries, that is, ideas and information on Physics, Science, Technology, Archaeology, Arts and Literatures. Physics at http://physics-sparavigna.blogspot.com
Zhang, X. & Phil, J. J. Drug-Eluting Bioresorbable Stents, Med-Tech Innovation (http://www.med-techinnovation.com).
Ali, M. N. , & Rehman, I. U. (2011). An Auxetic structure configured as oesophageal stent with potential to be used for palliative treatment of oesophageal cancer; development and in vitro mechanical analysis. J Mater. Sci.: Mater. Med., 22, 2573–2581. 10.1007/s10856-011-4436-y.
Scarpa, F. , Smith, C. W. , Ruzzene, M. , & Wadee, M. K. (2008). Mechanical properties of auxetic tubular trusslike structures. Physica Status Solidi (b), 245(3), 584–590.
Raamachandran, J. , & Jayavenkateshwaran, K. (2007). Modeling of stents exhibiting negative Poisson's ratio effect. Computer Methods in Biomechanics and Biomedical Engineering, 10(4), 245–255. 10.1080/10255840701198004
Baker, C. E. (2011). Auxetic Spinal Implants: Consideration of Negative Poisson's Ratio in the Design of an Artificial Intervertebral Disc (Thesis, Master of Science, University of Toledo).
Hengelmolen, R. (2004). AU2003249001.
Bhullar, S. K. , & Jun, M. B. G. (2013). In: Proc. International Workshop on Smart Materials & Structures. SHM and NDT for the Energy Industry, p. 1.
Jun, P. & Koo, K. (2013). The effect of negative poisson's ratio polyurethane scaffolds for articular cartilage tissue engineering applications. J. Advances in Materials Science and Engineering, ID853289. 10.1155/2013/853289
Fozdar, D. Y. , Soman, P. , Lee, J. W. , Han, L. H. , & Chen, S. (2011). Three-dimensional polymer constructs exhibiting a tunable negative Poisson's ratio. Advance Functional Material, 21, 2712. 10.1002/adfm.201002022
Soman, P. , Lee, J. W. , Phadke, A. , Varghese, S. , & Chen, S. (2012). Spatial tuning of negative and positive Poisson's ratio in a multi-layer scaffold. Acta Biomaterialia, 8(7), 2587–2594.
Yong, P. , Shiwu, D. , Yong, H. , Tongwei, C. , Changqing, L. , Zhengfeng, Z. , & Yue, Z. (2010). Demineralized bone matrix gelatin as scaffold for tissue engineering. African Journal of Microbiology Research, 4(9), 865–870.

Pagliara, S. , Franze, K. , McClain, C. R. , et al. (2014 Jun). Auxetic nuclei in embryonic stem cells exiting pluripotency. Nature Materials, 13(6), 638–644. 10.1038/nmat3943. PMID: 24747782; PMCID: PMC4283157.

Alderson, K. L. , & Evans, K. E. (1992). The fabrication of microporous polyethylene having a negative Poisson's ratio. Polymer, 33(20), 4435–4438.

Chludzinski, M. & Hammill, E. (2005). US Patent 6837890.

Choi, J. B. , & Lakes, R. S. (1992). Non-linear properties of metallic cellular materials with a negative Poisson's ratio. Journal of Materials Science, 27(19), 5375–5381.

Simkins, V. R. , Alderson, A. , Davies, P. J. , & Alderson, K. L. (2005). Single fibre pullout tests on auxetic polymeric fibres. Journal of Materials Science, 40(16), 4355–4364.

Evans, K. E. , Alderson, A. , & Christian, F. R. (1995). Auxetic two-dimensional polymer networks. An example of tailoring geometry for specific mechanical properties. Journal of the Chemical Society, Faraday Transactions, 91(16), 2671–2680.

Bhattacharjee, S. , Joshi, R. , Yasir, M. , Adhikari, A. , Chughtai, A. A. , Heslop, D. , Bull, R. , Mark Willcox, M. , & Macintyre, C. R. (2021). Graphene- and nanoparticle-embedded antimicrobial and biocompatible cotton/silk fabrics for protective clothing. ACS Applied Bio Materials, 4(8), 6175–6185. 10.1021/acsabm.1c00508

Liu, Y. , Hu, H. , Lam, J. K. , & Liu, S. (2010). Negative Poisson's ratio weft-knitted fabrics. Textile Research Journal, 80(9), 856–863.

Miller, W. , Hook, P. B. , Smith, C. W. , Wang, X. , & Evans, K. E. (2009). The manufacture and characterisation of a novel, low modulus, negative Poisson's ratio composite. Composites Science and Technology, 69(5), 651–655.

Alderson, A. , Rasburn, J. , Ameer-Beg, S. G. , Mullarkey, P. , Perrie, W. , & Evans, K. E. (2000). An auxetic filter: A tuneable filter displaying enhanced size selectivity or defouling properties. Industrial & Engineering Chemistry Research, 39(3), 654–665. 10.1021/ie990572w

Alderson, A. , Rasburn, J. , & Evans, K. E. (2007). Mass transport properties of auxetic (negative Poisson's ratio) foams. Physica Status Solidi (b), 244(3), 817–827.

Alderson, A. , Davies, P. J. , Evans, K. E. , Alderson, K. L. , & Grima, J. N. (2005). Modelling of the mechanical and mass transport properties of auxetic molecular sieves: An idealised inorganic (zeolitic) host–guest system. Molecular Simulation, 31(13), 889–896.

Langer, R. , & Vacanti, J. P. (1993). Tissue Eengineering. Science, 5110, 920–926. 10.1126/science.8493529

Lee, S. J. , Yoo, J. J. , & Atala, A. (2018). Biomaterials and tissue engineering. In:Kim, B. (eds), Clinical Regenerative Medicine in Urology, pp. 17−51, Springer, Singapore.

Ruskowitz, E. R. , & DeForest, C. A. (2018). Photoresponsive biomaterials for targeted drug delivery and 4D cell culture. Nat. Rev. Mater., 3(2), 17087.

Bhar, B. , Chouhan, D. , Pai, N. , & Mandal, B. B. (2021). Harnessing multifaceted next-generation technologies for improved skin wound healing. ACS Applied Bio Materials, 4(11), 7738–7763. 10.1021/acsabm.1c00880

Truong, V. X. , Ablett, M. P. , Richardson, S. M. , Hoyland, J. A. , & Dove, A. P. (2015). Simultaneous orthogonal dual-click approach to tough, in-situ-forming hydrogels for cell encapsulation. J. Am. Chem. Soc., 137(4), 1618−1622.

Sadtler, K. , Singh, A. , Wolf, M. T. , Wang, X. , Pardoll, D. M. , & Elisseeff, J. H. (2016). Design, clinical translation and immunological response of biomaterials in regenerative medicine. Nat. Rev. Mater., 1(7), 16040.

Zhang, Y. S. , & Khademhosseini, A. (2017). Advances in engineering hydrogels. Science (Washington, DC, U. S.), 356(6337), eaaf3627.

Eslahi, N. , Abdorahim, M. , & Simchi, A. (2016). Smart polymeric hydrogels for cartilage tissue engineering: A review on the chemistry and biological functions. Biomacromolecules, 17(11), 3441−3463.

Zhao, X. (2014). Multi-scale multi-mechanism design of tough hydrogels: Building dissipation into stretchy networks. Soft Matter, 10(5), 672−687.

Akhtar, M. F. , Hanif, M. , & Ranjha, N. M. (2016). Methods of synthesis of hydrogels − A review. Saudi Pharm. J., 24(5), 554−559.

Parhi, R. (2017). Cross-linked hydrogel for pharmaceutical applications: A review. Adv. Pharm. Bull., 7(4), 515−530.

Liu, M. , Zeng, X. , Ma, C. , Yi, H. , Ali, Z. , Mou, X. , Li, S. , Deng, Y. , & He, N. (2017). Injectable hydrogels for cartilage and bone tissue engineering. Bone Res., 5, 17014.

Razzaq, M. Y. , Behl, M. , & Lendlein, A. (2012). Memory-effects of magnetic nanocomposites. Nanoscale, 4(20), 6181−6195.
Balk, M. , Behl, M. , Wischke, C. , Zotzmann, J. , & Lendlein, A. (2016). Recent advances in degradable lactide-based shape-memory polymers. Adv. Drug Delivery Rev., 107, 136−152.
Behl, M. , Razzaq, M. Y. , & Lendlein, A. (2010). Multifunctional shape-memory polymers. Adv. Mater., 22(31), 3388−3410.
Neffe, A. T. , Hanh, B. D. , Steuer, S. , & Lendlein, A. (2009). Polymer networks combining controlled drug release, biodegradation, and shape memory capability. Adv Mater, 21 (32−33), 3394−3398.
Kuang, X. , Chen, K. , Dunn, C. K. , Wu, J. , Li, V. C. F. , & Qi, H. J. (2018). 3D printing of highly stretchable, shape-memory, and self-healing elastomer toward novel 4D printing. ACS Appl. Mater. Interfaces, 10(8), 7381−7388.
Kim, H. , Kim, S. , Lim, D. , & Jeong, W. (2022). Development and characterization of embroidery-based textile electrodes for surface EMG detection. Sensors (Basel, Switzerland), 22(13), 4746. 10.3390/s22134746
Mi, L. , Bernards, M. T. , Cheng, G. , Yu, Q. , & Jiang, S. (2010). PH responsive properties of non-fouling mixed-charge polymer brushes based on quaternary amine and carboxylic acid monomers. Biomaterials, 31(10), 2919−2925.
Yu, Q. , Wu, Z. , & Chen, H. (2015). Dual-function antibacterial surfaces for biomedical applications. Acta Biomater., 16, 1−13.
Anderson, J. M. , Rodriguez, A. , & Chang, D. T. (2008). Foreign body reaction to biomaterials. Semin. Immunol., 20(2), 86−100.
Wick, G. , Grundtman, C. , Mayerl, C. , Wimpissinger, T.-F. , Feichtinger, J. , Zelger, B. , Sgonc, R. , & Wolfram, D. (2013). The immunology of fibrosis. Annual Reviews, 31, 104−135.
Wynn, T. A. , & Ramalingam, T. R. (2012). Mechanisms of fibrosis: Therapeutic translation for fibrotic disease. Nat. Med., 18 (7), 1028−1040.
Ward, W. K. (2008). A review of the foreign-body response to subcutaneously-implanted devices: The role of macrophages and cytokines in biofouling and fibrosis. J. Diabetes Sci. Technol., 2(5), 768−777.
Sahdev, P. , Ochyl, L. J. , & Moon, J. J. (2014). Biomaterials for nanoparticle vaccine delivery systems. Pharm. Res., 31(10), 2563−2582.
Shao, K. , Singha, S. , Clemente-Casares, X. , Tsai, S. , Yang, Y. , & Santamaria, P. (2015). Nanoparticle-based immunotherapy for cancer. ACS Nano, 9(1), 16−30.
Andorko, J. I. , Hess, K. L. , & Jewell, C. M. (2015). Harnessing biomaterials to engineer the lymph node microenvironment for immunity or tolerance. AAPS J., 17(2), 323−338.
Sharp, F. A. , Ruane, D. , Claass, B. , Creagh, E. , Harris, J. , Malyala, P. , Singh, M. , O'Hagan, D. T. , Petrilli, V. , Tschopp, J. , et al. (2009). Uptake of particulate vaccine adjuvants by dendritic cells activates the NALP3 inflammasome. Proc. Natl. Acad. Sci. U. S. A., 106(3), 870−875.
Tang, L. , Zheng, Y. , Melo, M. B. , Mabardi, L. , Castanõ, A. P. , Xie, Y.-Q. , Li, N. , Kudchodkar, S. B. , Wong, H. C. , Jeng, E. K. , et al. (2018). Enhancing T cell therapy through TCR-signaling-responsive nanoparticle drug delivery. Nat. Biotechnol. 36(8), 707–716. 10.1038/nbt.4181.
Mchugh, K. J. , Nguyen, T. D. , Yang, D. , Behrens, A. M. , Rose, S. , Tochka, Z. L. , Tzeng, S. Y. , Norman, J. J. , Tomasic, S. , Taylor, M. A. , et al. (2017). Fabrication of fillable microparticles and other complex 3D microstructures. Science, 357, 1138−1142.
Morrison, C. (2018). Alnylam prepares to land first RNAi drug approval. Nat. Rev. Drug Discovery, 17(3), 156−157.
Yin, H. , Kauffman, K. J. , & Anderson, D. G. (2017). Delivery technologies for genome editing. Nat. Rev. Drug Discovery, 16(6), 387−399.
Kowalski, P. S. , Capasso Palmiero, U. , Huang, Y. , Rudra, A. , Langer, R. , Anderson, D. G. (2018). Ionizable amino-polyesters synthesized via ring opening polymerization of tertiary amino-alcohols for tissue selective MRNA delivery. Adv. Mater., 30(34), 1801151.
ur Rehman, Z. , Hoekstra, D. , & Zuhorn, I. S. (2013). Mechanism of polyplex- and lipoplex-mediated delivery of nucleic acids: Real-time visualization of transient membrane destabilization without endosomal lysis. ACS Nano, 7(5), 3767−3777.
Rehman, Z. , Zuhorn, I. S. , & Hoekstra, D. (2013). How cationic lipids transfer nucleic acids into cells and across cellular membranes: Recent advances. J. Controlled Release, 166(1), 46−56.

Jaraswekin, S. , Prakongpan, S. , & Bodmeier, R. (2007). Effect of poly(lactide-co-glycolide) molecular weight on the release of dexamethasone sodium phosphate from microparticles, Journal of Microencapsulation, 24(2), 117. 10.1080/02652040701233655

Winkler, J. S. , Barai, M. , & Tomassone M. S. (2019). Dual drug-loaded biodegradable Janus particles for simultaneous co-delivery of hydrophobic and hydrophilic compounds. Experimental Biology and Medicine, 244(14), 1162–1177. 10.1177/1535370219876554.

Kumar, N. , Fazal, S. , Miyako, E. , Matsumura, K. , & Rajan, R. (2021). Avengers against cancer: A new era of nano-biomaterial-based therapeutics. Materials Today, 51, 317–349, ISSN 1369-7021, 10.1016/j.mattod.2021.09.020. (https://www.sciencedirect.com/science/article/pii/S1369702121003321).

Yechezkel (Chezy) Barenholz (2012). Doxil® — The first FDA-approved nano-drug: Lessons learned. Journal of Controlled Release, 160(2), 117–134, ISSN 0168-3659, 10.1016/j.jconrel.2012.03.020

Khan, M. I. , Hossain, M. I. , Hossain, M. K. , Rubel, M. , Hossain, K. M. , Mahfuz, A. , & Anik, M. I. (2022). Recent progress in nanostructured smart drug delivery systems for cancer therapy: A review. ACS Applied Bio Materials, 5(3), 971–1012. 10.1021/acsabm.2c00002

Naidu, N. , Wadher, K. , & Umekar, M. (2021). An overview on biomaterials: Pharmaceutical and biomedical applications. Journal of Drug Delivery and Therapeutics, 11, 154–161. 10.22270/jddt.v11i1-s.4723.

Davis, J. R. (ed.) (2003). Overview of biomaterials and their use in medical devices, In: Handbook of Materials for Medical Devices, 1–11, ASM International, United States.

Phyo, J. B. , Woo, A. , Yu, H. J. , Lim, K. , Cho, B. H. , Jung, H. S. , & Lee, M.-Y. (2021). Analytical Chemistry, 93(8), 3778–3785. 10.1021/acs.analchem.0c04200

Zhao, W. , Cui, C. H. , Bose, S. , Guo, D. , Shen, C. , Wong, W. P. , Halvorsen, K. , Farrokhzad, O. C. , Sock, G. , & Teo, L. (2012). Bioinspired multivalent DNA network for capture and release of cells. Proc. Natl. Acad. Sci. U. S. A., 109, 19626.

Capasso Palmiero, U. , Sponchioni, M. , Manfredini, N. , Maraldi, M. , & Moscatelli, D. (2018). Strategies to combine ROP with ATRP or RAFT polymerization for the synthesis of biodegradable polymeric nanoparticles for biomedical applications. Polym. Chem., 9, 4084.

Sharma, R. , Sharma, D. , Hazlett, L. D. , & Singh, N. K. (2021). Nano-biomaterials for retinal regeneration. Nanomaterials, 11, 1880. 10.3390/nano11081880

Ferroelectric Polymer Composites and Evaluation of Their Properties

Gefle, O. S. , Lebedev, S. M. , and Pokholkov, Y. P. 2007. Barrier effect in dielectrics. Tomsk: TML-Press (in Russian).

Gefle, O. S. , Lebedev, S. M. , and Uschakov, V. Y. 1997. The mechanism of the barrier effect in solid dielectrics. J Phys D: Appl Phys 30:3267–3273.

Chen, Q. , Shen, Y. , Zhang, S. , et al. 2015. Polymer-based dielectrics with high storage energy density. Ann Rev Mater Res 45:433–458.

Fan, Y. , Huang, X. , Wang, G. , et al. 2015. Core-shell structured biopolymer@BaTiO3 nanoparticles for biopolymer nanocomposites with significantly enhanced dielectric properties and energy storage capability. J Phys Chem C 119:27330. 10.1021/acs.jpcc.5b09619

Yamashita, T. , Okada, H. , Itoh, T. , et al. 2015. Manufacturing process for piezoelectric strain sensor sheet involving transfer printing methods. Jpn J Appl Phys 54:10ND08. 10.7567/JJAP.54.10ND08

Ruschau, G. R. , Newham, R. E. , Runt, J. , et al. 1989. 0–3 ceramic-polymer composite chemical sensors. Sens Actuators 20:269–275.

Post, J. E. 2005. Microwave performance of MCM-D embedded capacitors with interconnects. Microwave and Optical Technol Lett 46:487–492.

Ni, Q.-Q. , Zhu, Y.-F. , Yu, L.-J. , et al. 2015. One-dimensional carbon nanotube@barium titanate@polyaniline multiheterostructures for microwave absorbing application. Nanoscale Res Lett 10:174–181. 10.1186/s11671-015-0875-6

Kapat, K. , Shubhra, Q. T. H. , Zhou, M. , et al. 2020. Piezoelectric nano-biomaterials for biomedicine and tissue regeneration. Adv Funct Mater 30:1909045. 10.1002/adfm.201909045

Jacob, J. , More, N. , Kalia, K. , and Kapusetti, G. 2018. Piezoelectric smart biomaterials for bone and cartilage tissue engineering. Inflammation and Regeneration 38:2–10. 10.1186/s41232-018-0059-8

Li, Y. , Dai, X. , Bai, Y. , et al. 2017. Electroactive $BaTiO_3$ nanoparticle-functionalized fibrous scaffolds enhance osteogenic differentiation of mesenchymal stem cells. Int J Nanomedicine 12:4007–4018.

Rajabi, A. H. , Jaffe, M. , and Arinzeh, T. L. 2015. Piezoelectric materials for tissue regeneration: A review. Acta Biomaterialia 24:12–23. 10.1016/j.actbio.2015.07.010

Kemppi, H. , Finnilä, M. A. , Lorite, G. S. , et al. 2021. Design and development of poly-L/D-lactide copolymer and barium titanate nanoparticle 3D composite scaffolds using breath figure method for tissue engineering applications. Colloids and Surfaces B: Biointerfaces 199:111530. 10.1016/j.colsurfb.2020.111530

Lewis, T. J. 2004. In Interfaces and nanodielectrics are synonymous. Proc. Int. Conf. Solid Diel., Toulouse, July 5–9, 2004, pp. 792–795.

Tanaka, T. 2005. Dielectric nanocomposites with insulating properties. IEEE Trans Dielect Electr Insul 12:914–928.

Gojny, F. H. , Wichmann, M. H. G. , Fiedler, B. , et al. 2006. Evaluation and identification of electrical and thermal conduction mechanisms in carbon nanotube/epoxy composites. Polymer 47:2036–2045.

Wischke, C. , and Lendlein, A. 2010. Shape-memory polymers as drug carriers – A multifunctional system. Pharmaceutical Research 27:527–529.

Liu, L. , and Grunlan, J. C. 2007. Clay assisted dispersion of carbon nanotubes in conductive epoxy nanocomposites. Adv Funct Mater 17:2343–2348. 10.1002/adfm.200600785

Miriyala, S. M. , Kim, Y. S. , Liu, L. , et al. 2008. Segregated network of carbon black in poly(vinyl acetate) latex: Influence of clay on the electrical and mechanical behavior. Marcomol Chem Phys 209:2399–2409. 10.1002/macp.200800384

Lebedev, S. M. , Gefle, O. S. , Amitov, E. T. , et al. 2016. Conductive carbon nanotube-reinforced polymer composites and their characterization. IEEE Trans Diel Elect Ins 23:1723–1731.

Lebedev, S. M. , Gefle, O. S. , Amitov, E. T. , et al. 2017. Poly(lactic acid)-based polymer composites with high electric and thermal conductivity and their characterization. Polym Test 58:241–248. 10.1016/j.polymertesting.2016.12.033

Vert, M. , Santos, I. D. , Ponsart, S. , et al. 2002. Degradable polymers in a living environment: Where do you end up? Polym Int 51:840–844.

Sinclair, R. G. 1996. The case for polylactic acid as a commodity packaging plastic. J Macromol Sci Part A: Pure Appl Chem 33:585–597.

Vainionpaa, S. , Rokkanen, P. , and Tormala, P. 1989. Surgical applications of biodegradable polymers in human tissues. Prog Polym Sci 14:679–716.

Jong, W. H. D. , Bergsma, J. E. , Robinson, J. E. , et al. 2005. Tissue response to partially in vitro predegraded poly-L-lactide implants. Biomaterials 26:1781–1791.

Langer, R. , and Vacanti, J. P. 1993. Tissue engineering. Science 260:920–926.

Gupta, A. P. , and Kumar, V. 2007. New emerging trends in synthetic biodegradable polymers – Polylactide: A critique. Europ Polym J 43:4053–4074.

Gupta, B. , Revagade, N. , and Hilborn, J. 2007. Poly(lactic acid) fiber: An overview. Prog Polym Sci 32:455–482.

Luckachan, G. E. , and Pillai, C. K. S. 2011. Biodegradable polymers - A review on recent trends and emerging perspectives. J Polym Environ 19:637–676.

Sullivan, E. M. , Gerhardt, R. A. , Wang, B. , et al. 2016 Effect of compounding method and processing conditions on the electrical response of exfoliated graphite nanoplatelet/polylactic acid nanocomposite films. J Mater Sci 51:2980–2990.

Hayashi, S. , Kondo, S. , Kapadia, P. , et al. 1995. Room-temperature-functional shape memory polymers. Plastics Engineering 51:29–31.

Ratna, D. , and Karger-Kocsis, J. 2008. Recent advances in shape memory polymers and composites: A review. J Mater Sci 43:254–269.

Wul, B. M. 1946. Substances with high and ultra-high dielectric constant. Electricity 3:12–20 (in Russian).

Wul, B. M. , and Goldman, I. M. 1945. Dielectric constant of barium titanate depending on the intensity under AC field. Dokl Akad Nauk USSR 49:179–182 (in Russian).

Yasuda, I. 1954. On the piezoelectric property of bone. J Jpn Orthop Surg Soc 28:267–279.
Fukada, E. , and Yasuda, I. 1957. On the piezoelectric effect of bone. J Phys Soc Jpn 12:1158–1162.
Bassett, C. A. L. 1967. Biologic significance of piezoelectricity. Calcified Tissue Res 1:252–272.
Supronowicz, P. R. , Ajayan, P. M. , Ullmann, K. R. , et al. 2002. Novel current-conducting composite substrates for exposing osteoblasts to alternating current stimulation. J Biomed Mater Res 59:499–506. 10.1002/jbm.10015
Sitharaman, B. , Shi, X. , Walboomers, H. F. , et al. 2008. In vivo biocompatibility of ultra-short single-walled carbon nanotube/biodegradable polymer nanocomposites for bone tissue engineering. Bone 43:362–370. 10.1016/j.bone.2008.04.013
Nawanil, C. , Panprom, P. , Khaosa-Ard, K. , et al. 2010. Effect of surface treatment on electrical properties of barium titanate/carbon nanotube/polydimethylsiloxane nanocomposites. Int Conf Sci Technol Emerging Mater, AIP Conf Proc, pp. 020029-1–020029-7. 10.1063/1.5053205
Dang, Z.-M. , Yao, S.-H. , Yuan, J.-K. , et al. 2010. Tailored dielectric properties based on microstructure change in BaTiO3-carbon nanotube/polyvinylidene fluoride three-phase nanocomposites. J Phys Chem C 114:13204–13209. 10.1021/jp103411c
Sawyer, C. B. , and C. H. Tower . 1930. Rochele salt as a dielectric. Phys Rev 35:269–273.
Bruggeman, D. A. G. 1935. Berechnung verschiedener physikalischer Konstanten von heterogenen Substanzen. Ann Phys Lpz 24:636–679.
Gefle, O. S. , Lebedev, S. M. , Pokholkov, Y. P. , Tkachenko, S. N. , Volokhin, V. A. , Cherkashina, E. I. 2005. In Study of dielectric relaxation of composite materials by the dielectric spectroscopy method. Proc. ISEIM'05, Kitakyushu, Japan, 5–9 June, 2005, Vol. 3, pp. 85–87.
Bogoroditskiy, N. P. , Volokobinskiy, Y. M. , Vorob'ev, A. A. , et al. 1965. Theory of dielectrics. Moscow-Energy (in Russian).
Mancuso, E. , Shah, L. , Jindal, S. , et al. 2021. Additively manufactured BaTiO3 composite scaffolds: A novel strategy for load bearing bone tissue engineering applications. Mater Sci Eng C 126:112192. 10.1016/j.msec.2021.112192
Ribeiro, C. , Sencadas, V. , Correia, D. M. , et al. 2015. Piezoelectric polymers as biomaterials for tissue engineering applications. Colloids and Surfaces B: Biointerfaces 136:46–55. 10.1016/j.colsurfb.2015.08.043
Tandon, B. , Blaker, J. J. , and Cartmell, S. H. 2018. Piezoelectric materials as stimulatory biomedical materials and scaffolds for bone repair. Acta Biomaterialia 73:1–20. 10.1016/j.actbio.2018.04.026
Kharitonov, E. V. 1983. Dielectric materials with inhomogeneous structure. Moscow: Radio and Communication (in Russian).
Stauffer, D. , and Aharony, A. 1992. Introduction to percolation theory. London: Taylor and Francis, 2nd Ed.
Kapitza, P. L. 1965. Collected papers of P. L. Kapitza . D. ter Haar (Ed.), Vol. 2, Oxford: Pergamon Press.
Shenogin, S. , Xue, L. , Ozisik, R. , et al. 2004. Role of thermal boundary resistance on the heat flow in carbon-nanotube composites. J Appl Phys 95:8136–8144.
Lee, K. H. , Kao, J. , Parizi, S. S. , et al. 2014. Dielectric properties of barium titanate supramolecular nanocomposites. Nanoscale. 6:3526–3531.
Hammami, H. , Arous, M. , Lagache, M. , et al. 2006. Experimental study of relaxations in unidirectional piezoelectric composites. Composites: Part A 37:1–8.
Upadhyay, R. H. , Argekar, A. P. , and Deshmukh, R. R. 2014. Characterization, dielectric and electrical behaviour of BaTiO3 nanoparticles prepared via titanium(IV) triethanolaminato isopropoxide and hydrated barium hydroxide. Bull Mater Sci 37:481–489.
Curecheriu, L. , Balmus, S.-B. , Buscaglia, M. T. , et al. 2012. Grain size-dependent properties of dense nanocrystalline barium titanate ceramics. J Am Ceram Soc 95:3912–3921. 10.1111/j.1551-2916.2012.05409.x
Walker, E. , Akishige, Y. , Cai, T. , et al. 2019. Maxwell-Wagner-Sillars dynamics and enhanced radio-frequency elastomechanical susceptibility in PNIPAm hydrogel-KF-doped barium titanate nanoparticle composites. Nanoscale Res Lett 14:385–396. 10.1186/s11671-019-3171-z
Jonscher, A. K. 1996. Universal relaxation law. London: Chelsea Dielectric Press.

4D Print Today and Envisaging the Trend with Patent Landscape for Versatile Applications

Hull, C.W. , UVP Inc , 1986. Apparatus for production of three-dimensional objects by stereolithography. U.S. Patent 4,575,330.

Prince, J.D. , 2014. 3D printing: An industrial revolution. Journal of Electronic Resources in Medical Libraries, 11(1), pp. 39–45.

Nickels, L. , 2015. AM and aerospace: An ideal combination. Metal Powder Report, 70(6), pp. 300–303.

Tetsuka, H. and Shin, S.R. , 2020. Materials and technical innovations in 3D printing in biomedical applications. Journal of Materials Chemistry B, 8(15), pp. 2930–2950.

Tay, Y.W.D. , Panda, B. , Paul, S.C. , Noor Mohamed, N.A. , Tan, M.J. and Leong, K.F. , 2017. 3D printing trends in building and construction industry: A review. Virtual and Physical Prototyping, 12(3), pp. 261–276.

Valentine, A.D. , Busbee, T.A. , Boley, J.W. , Raney, J.R. , Chortos, A. and Kotikian, A. , 2017. JD 1204 Berrigan, MF Durstock, JA Lewis. Advanced Materials, 29(40), p. 1703817.

Pasricha, A. and Greeninger, R. , 2018. Exploration of 3D printing to create zero-waste sustainable fashion notions and jewelry. Fashion and Textiles, 5(1), pp. 1–18.

Tibbits, S. , 2013, February. The emergence of “4D printing”. In TED Conference.

Schattling, P. , Jochum, F.D. and Theato, P. , 2014. Multi-stimuli responsive polymers – The all-in-one talents. Polymer Chemistry, 5(1), pp. 25–36.

https://www.lexico.com/definition/4d_printing – Accessed on 7 July 2022.

Oladapo, B.I. , Oshin, E.A. and Olawumi, A.M. , 2020. Nanostructural computation of 4D printing carboxymethylcellulose (CMC) composite. Nano-Structures & Nano-Objects, 21, p. 100423.

Wang, F. , Yuan, C. , Wang, D. , Rosen, D.W. and Ge, Q. , 2020. A phase evolution based constitutive model for shape memory polymer and its application in 4D printing. Smart Materials and Structures, 29(5), p. 055016.

Oladapo, B.I. , Adebiyi, A.V. and Elemure, E.I. , 2021. Microstructural 4D printing investigation of ultra-sonication biocomposite polymer. Journal of King Saud University-Engineering Sciences, 33(1), pp. 54–60.

Han, M. , Yang, Y. and Li, L. , 2020. Energy consumption modeling of 4D printing thermal-responsive polymers with integrated compositional design for material. Additive Manufacturing, 34, p. 101223.

Mathews, A.S. , Abraham, S. , Kumaran, S.K. , Fan, J. and Montemagno, C. , 2017. Bio nano ink for 4D printing membrane proteins. RSC Advances, 7(66), pp. 41429–41434.

Bagheri, A. , Engel, K.E. , Bainbridge, C.W.A. , Xu, J. , Boyer, C. and Jin, J. , 2020. 3D printing of polymeric materials based on photo-RAFT polymerization. Polymer Chemistry, 11(3), pp. 641–647.

Bagheri, A. , Bainbridge, C.W.A. , Engel, K.E. , Qiao, G.G. , Xu, J. , Boyer, C. and Jin, J. , 2020. Oxygen tolerant PET-RAFT facilitated 3D printing of polymeric materials under visible LEDs. ACS Applied Polymer Materials, 2(2), pp. 782–790.

Zhang, Z. , Corrigan, N. , Bagheri, A. , Jin, J. and Boyer, C. , 2019. A versatile 3D and 4D printing system through photo controlled RAFT polymerization. Angewandte Chemie, 131(50), pp. 18122–18131.

Zhao, Z. , Tian, X. and Song, X. , 2020. Engineering materials with light: Recent progress in digital light processing based 3D printing. Journal of Materials Chemistry C, 8(40), pp. 13896–13917.

Huang, J. , Qin, Q. , and Wang, J. , 2020. A review of stereolithography: Processes and systems. Processes, 8(9), p. 1138.

Harinarayana, V. and Shin, Y.C. , 2021. Two-photon lithography for three-dimensional fabrication in micro/nanoscale regime: A comprehensive review. Optics & Laser Technology, 142, p. 107180.

Lewis, J.A. , 2006. Direct ink writing of 3D functional materials. Advanced Functional Materials, 16(17), pp. 2193–2204.

Fischer, F. , 2015. FDM and Polyjet 3D printing. Popular Plastics & Packaging, 60(6), pp. 1–7.

Mallakpour, S. , Tabesh, F. and Hussain, C.M. , 2021. 3D and 4D printing: From innovation to evolution. Advances in Colloid and Interface Science, 294, p.102482.

Patil, A.N. and Sarje, S.H. , 2021. Additive manufacturing with shape-changing/memory materials: A review on 4D printing technology. Materials Today: Proceedings, 44, pp. 1744–1749.
Huang, J. , Xia, S. , Li, Z. , Wu, X. and Ren, J. , 2021. Applications of four-dimensional printing in emerging directions: Review and prospects. Journal of Materials Science & Technology, 91, pp. 105–120.
Subeshan, B. , Baddam, Y. and Asmatulu, E. , 2021. Current progress of 4D-printing technology. Progress in Additive Manufacturing, 6(3), pp. 495–516.
Kumar, S.B. , Jeevamalar, J. , Ramu, P. , Suresh, G. and Senthilnathan, K. , 2021. Evaluation in 4D printing–a review. Materials Today: Proceedings, 45, pp. 1433–1437.
Mohol, S.S. and Sharma, V. , 2021. Functional applications of 4D printing: A review. Rapid Prototyping Journal, 27(8), pp. 1501–1522.
Ma, S. , Zhang, Y. , Wang, M. , Liang, Y. , Ren, L. and Ren, L. , 2020. Recent progress in 4D printing of stimuli-responsive polymeric materials. Science China Technological Sciences, 63(4), pp. 532–544.
Falahati, M. , Ahmadvand, P. , Safaee, S. , Chang, Y.C. , Lyu, Z. , Chen, R. , Li, L. and Lin, Y. , 2020. Smart polymers and nanocomposites for 3D and 4D printing. Materials Today, 40, pp. 215–245.
Peng, B. , Yang, Y. and Cavicchi, K.A. , 2020. Sequential shapeshifting 4D printing: Programming the pathway of multi-shape transformation by 3D printing stimuli-responsive polymers. Multifunctional Materials, 3(4), p. 042002.
González-Henríquez, C.M. , Sarabia-Vallejos, M.A. and Rodriguez-Hernandez, J. , 2019. Polymers for additive manufacturing and 4D-printing: Materials, methodologies, and biomedical applications. Progress in Polymer Science, 94, pp. 57–116.
Huang, X. , Panahi-Sarmad, M. , Dong, K. , Li, R. , Chen, T. and Xiao, X. , 2021. Tracing evolutions in electro-activated shape memory polymer composites with 4D printing strategies: a systematic review. Composites Part A: Applied Science and Manufacturing, 147, p. 106444.
Gauss, C. , Pickering, K.L. and Muthe, L.P. , 2021. The use of cellulose in bio-derived formulations for 3D/4D printing: A review. Composites Part C: Open Access, 4, p. 100113.
Le Duigou, A. , Correa, D. , Ueda, M. , Matsuzaki, R. and Castro, M. , 2020. A review of 3D and 4D printing of natural fibre biocomposites. Materials & Design, 194, p. 108911.
Mehrpouya, M. , Vahabi, H. , Janbaz, S. , Darafsheh, A. , Mazur, T.R. and Ramakrishna, S. , 2021. 4D printing of shape memory polylactic acid (PLA). Polymer, 230, p. 124080.
Andreu, A. , Su, P.C. , Kim, J.H. , Ng, C.S. , Kim, S. , Kim, I. , Lee, J. , Noh, J. , Subramanian, A.S. and Yoon, Y.J. , 2021. 4D printing materials for vat photopolymerization. Additive Manufacturing, 44, p. 102024.
Shie, M.Y. , Shen, Y.F. , Astuti, S.D. , Lee, A.K.X. , Lin, S.H. , Dwijaksara, N.L.B. and Chen, Y.W. , 2019. Review of polymeric materials in 4D printing biomedical applications. Polymers, 11(11), p. 1864.
Champeau, M. , Heinze, D.A. , Viana, T.N. , de Souza, E.R. , Chinellato, A.C. and Titotto, S. , 2020. 4D printing of hydrogels: A review. Advanced Functional Materials, 30(31), p. 1910606.
Miao, S. , Castro, N. , Nowicki, M. , Xia, L. , Cui, H. , Zhou, X. , Zhu, W. , Lee, S.J. , Sarkar, K. , Vozzi, G. and Tabata, Y. , 2017. 4D printing of polymeric materials for tissue and organ regeneration. Materials Today, 20(10), pp. 577–591.
Subash, A. and Kandasubramanian, B. , 2020. 4D printing of shape memory polymers. European Polymer Journal, 134, p. 109771.
Stutz, H. , Illers, K.H. and Mertes, J. , 1990. A generalized theory for the glass transition temperature of crosslinked and uncrosslinked polymers. Journal of Polymer Science Part B: Polymer Physics, 28(9), pp. 1483–1498.
Amin, A. , Sarkar, R. , Moorefield, C.N. and Newkome, G.R. , 2013. Preparation of different dendriticlayered silicate nanocomposites. Polymer Engineering & Science, 53(10), pp. 2166–2174.
Behl, M. and Lendlein, A. , 2007. Shape-memory polymers. Materials Today, 10(4), pp. 20–28.
Meng, Q. and Hu, J. , 2009. A review of shape memory polymer composites and blends. Composites Part A: Applied Science and Manufacturing, 40(11), pp. 1661–1672.
Small IV, W. , Singhal, P. , Wilson, T.S. and Maitland, D.J. , 2010. Biomedical applications of thermally activated shape memory polymers. Journal of Materials Chemistry, 20(17), pp. 3356–3366.

Leng, J. , Lan, X. , Liu, Y. and Du, S. , 2011. Shape-memory polymers and their composites: Stimulus methods and applications. Progress in Materials Science, 56(7), pp. 1077–1135.

Rosales, C.A.G. , Duarte, M.F.G. , Kim, H. , Chavez, L. , Hodges, D. , Mandal, P. , Lin, Y. and Tseng, T.L.B. , 2018. 3D printing of shape memory polymer (SMP)/carbon black (CB) nanocomposites with electro-responsive toughness enhancement. Materials Research Express, 5(6), p. 065704.

Le Duigou, A. , Castro, M. , Bevan, R. and Martin, N. , 2016. 3D printing of wood fibre biocomposites: From mechanical to actuation functionality. Materials & Design, 96, pp. 106–114.

Mulakkal, M.C. , Trask, R.S. , Ting, V.P. and Seddon, A.M. , 2018. Responsive cellulose-hydrogel composite ink for 4D printing. Materials & Design, 160, pp. 108–118.

Bakarich, S.E. , Gorkin III, R. , Panhuis, M.I.H. and Spinks, G.M. , 2015. 4D printing with mechanically robust, thermally actuating hydrogels. Macromolecular Rapid Communications, 36(12), pp. 1211–1217.

Yuan, C. , Wang, F. and Ge, Q. , 2021. Multimaterial direct 4D printing of high stiffness structures with large bending curvature. Extreme Mechanics Letters, 42, p. 101122.

Raviv, D. , Zhao, W. , McKnelly, C. , Papadopoulou, A. , Kadambi, A. , Shi, B. , Hirsch, S. , Dikovsky, D. , Zyracki, M. , Olguin, C. and Raskar, R. , 2014. Active printed materials for complex self-evolving deformations. Scientific Reports, 4(1), pp. 1–8.

Baker, A.B. , Bates, S.R. , Llewellyn-Jones, T.M. , Valori, L.P. , Dicker, M.P. and Trask, R.S. , 2019. 4D printing with robust thermoplastic polyurethane hydrogel-elastomer trilayers. Materials & Design, 163, p. 107544.

LópezValdeolivas, M. , Liu, D. , Broer, D.J. and SánchezSomolinos, C. , 2018. 4D-printed actuators with softrobotic functions. Macromolecular Rapid Communications, 39(5), p. 1700710.

Kotikian, A. , Truby, R.L. , Boley, J.W. , White, T.J. and Lewis, J.A. , 2018. 3D printing of liquid crystal elastomeric actuators with spatially programed nematic order. Advanced Materials, 30(10), p. 1706164.

Ambulo, C.P. , Burroughs, J.J. , Boothby, J.M. , Kim, H. , Shankar, M.R. and Ware, T.H. , 2017. Four-dimensional printing of liquid crystal elastomers. ACS Applied Materials & Interfaces, 9(42), pp. 37332–37339.

Saed, M.O. , Ambulo, C.P. , Kim, H. , De, R. , Raval, V. , Searles, K. , Siddiqui, D.A. , Cue, J.M.O. , Stefan, M.C. , Shankar, M.R. and Ware, T.H. , 2019. Molecularlyengineered, 4Dprinted liquid crystal elastomer actuators. Advanced Functional Materials, 29(3), p. 1806412.

Barnes, M. , Sajadi, S.M. , Parekh, S. , Rahman, M.M. , Ajayan, P.M. and Verduzco, R. , 2020. Reactive 3D printing of shape-programmable liquid crystal elastomer actuators. ACS Applied Materials & Interfaces, 12(25), pp. 28692–28699.

Zhang, C. , Lu, X. , Fei, G. , Wang, Z. , Xia, H. and Zhao, Y. , 2019. 4D printing of a liquid crystal elastomer with a controllable orientation gradient. ACS Applied Materials & Interfaces, 11(47), pp. 44774–44782.

Yuan, C. , Roach, D.J. , Dunn, C.K. , Mu, Q. , Kuang, X. , Yakacki, C.M. , Wang, T.J. , Yu, K. and Qi, H.J. , 2017. 3D printed reversible shape changing soft actuators assisted by liquid crystal elastomers. Soft Matterials, 13(33), pp. 5558–5568.

Roach, D.J. , Kuang, X. , Yuan, C. , Chen, K. and Qi, H.J. , 2018. Novel ink for ambient condition printing of liquid crystal elastomers for 4D printing. Smart Materials and Structures, 27(12), p. 125011.

Fu, P. , Li, H. , Gong, J. , Fan, Z. , Smith, A.T. , Shen, K. , Khalfalla, T.O. , Huang, H. , Qian, X. , McCutcheon, J.R. and Sun, L. , 2022. 4D printing of polymeric materials: Techniques, materials, and prospects. Progress in Polymer Science, p. 101506.

https://patentscope.wipo.int/search/en/result.jsf?_vid=P21-L6BXPJ-55799. Accessed on 2 August 2022.

The George Washington University , 2022. “US20220204927” – 4D printing smart culture substrate for cell growth.

The University of Akron , 2022. WO2022055558” “Resorbable complex shape memory poly (propylene fumarate) star scaffolds for 4d printing applications.

Investigating the Work Generation Potential of SMA Wire Actuators

Motzki, P. , and Seelecke, S. 2022. Industrial applications for shape memory alloys, In Encyclopedia of Smart Materials, ed. Olabi, A. G. , 254–266. Elsevier. 10.1016/B978-0-12-803581-8.11723-0

Patel, S. K. , Behera, B. , Swain, B. , Roshan, R. , Sahoo, D. , and Behera, A. 2020. A review on NiTi alloys for biomedical applications and their biocompatibility. Materials Today: Proceedings 33, No. 8: 5548–5551. 10.1016/j.matpr.2020.03.538

Goergen, Y. , Chadda, R. , Britz, R. , Scholtes, D. et al. 2019. Shape memory alloys in continuum and soft robotic applications. In *Proceedings of the ASME 2019 Conference on Smart Materials, Adaptive Structures, and Intelligent Systems* . Louisville, Kentucky, USA. 9–11 September, pp. 1–6. 10.1115/SMASIS2019-5610

Riccio, A. , Sellitto, A. , Ameduri, S. , Concilio, A. , and Arena, M. 2021. Shape memory alloys (SMA) for automotive applications and challenges, In Shape Memory Alloy Engineering (Second edition), ed. Concilio, A. , Antonucci, V. , Auricchio, F. , Lecce, L. , and Sacco, E. , 785–808. Butterworth-Heinemann. 10.1016/B978-0-12-819264-1.00024-8

Materials . 2018. Shape memory alloy achieve high force and precision. https://www.techbriefs.com/component/content/article/tb/pub/features/articles/29019

Tanaka, K. 1986. A thermo-mechanical sketch of shape memory effect: One-dimensional tensile behavior. Res Mechanica 18, 251–263.

Liang, C. , and Rogers, C. A. 1990. One dimensional thermomechanical constitutive relations for shape memory materials. Journal of Intelligent Material Systems and Structures 1, 207–234. 10.1177/1045389X9000100205

Brinson, L. C. 1993. One-dimensional constitutive behavior of shape memory alloys: Thermo mechanical derivation with non-constant material functions and re-defined martensite internal variable. Journal of Intelligent Material Systems and Structures 4, No. 2: 229–242. 10.1177%2F1045389X9300400213

Banerjee, A. 2012. Simulation of shape memory alloy wire actuator behavior under arbitrary thermo-mechanical loading. Smart Materials and Structures 21, No. 125018: 1–13. 10.1088/0964-1726/21/12/125018

Gurung, H. 2017. Self-sensing shape memory alloy wire actuators using Kalman filters, (accession no. TH-1636) Ph.D. diss., Indian Institute of Technology Guwahati, India. http://gyan.iitg.ernet.in/handle/123456789886

Bhatt, N. , Soni, S. , and Singla, A. 2021. Comparative analysis of numerical methods for constitutive modeling of shape memory alloys. Modeling and Simulation in Materials Science and Engineering 29, No. 8: 1–23. 10.1088/1361-651X/ac3052

Bhatt, N. , Soni, S. , and Singla, A. 2022. Analyzing the effect of parametric variations on the performance of antagonistic SMA spring actuator, Materials Today Communications 31, No. 103728: 1–13.10.1016/j.mtcomm.2022.103728

Gao, X. , Qiao, R. , and Brinson, L. C. , 2007. Phase diagram kinetics for shape memory alloys: A robust finite element implementation. Smart Materials and Structures 16, 2102–2115. 10.1088/0964-1726/16/6/013

Alipour, A. Kadkhodaei, M. , and Ghaei, A. 2015. Finite element simulation of shape memory alloy wires using a user material subroutine: Parametric study on heating rate, conductivity, and heat convection. Journal of Intelligent Material Systems and Structures 26, No. 5: 554–572. 10.1177%2F1045389X14533431

Zhou, B. , Kang, Z. , Wang, Z. , and Xue, S. 2019. Finite element method on shape memory structure and its applications, Chinese Journal of Mechanical Engineering 32, No. 84: 1–11. 10.1186/s10033-019-0401-3

Copaci, D. , Blanco, D. , Clemente, A. M. , and Moreno, L. 2020. Flexible shape memory alloy actuators for soft robotics: Modelling and control, International Journal of Advanced Robotic Systems 17(1), 1–15. 10.1177%2F1729881419886747

Pillai, R. R. , Murali, G. , and Gopal, M. 2018. Modeling and simulation of a shape memory alloy spring actuated flexible parallel manipulator, Procedia Computer Science 133, 895–904. 10.1016/j.procs.2018.07.104

Zhang, D. , Zhao, X. , Han, J. , Li, X. , and Zhang, B. 2019. Active modeling and control for shape memory alloy actuators, IEEE Access 7, 162549–162558. 10.1109/ACCESS.2019.2936256
Hadi, A. , Akbari, H. , Tarvirdizadeh, B. , and Alipour, K. 2016. Developing a novel continuum module actuated by shape memory alloys, Sensors and Actuators A: Physical 243, 90–102. 10.1016/j.sna.2016.03.019
Lu, Y. , Zhang, R. , Xu, Y. , Wang, L. , and Yue, H. , Resistance characteristics of SMA actuator based on the variable speed phase transformation constitutive model. Materials 13, No. 6: 1–11. 10.3390/ma13061479
Todorov, T. , Mitrev, R. , Yatchev, I. , Fursov, A. , Ilin, A. , and Fomichev, V. 2020. A parametric study of an electrothermal oscillator based on shape memory alloys. In *21st International Symposium on Electrical Apparatus & Technologies (SIELA)* , Bourgas, Bulgaria. 3–6 June 2020, pp. 1–4. 10.1109/SIELA49118.2020.9167127

Troubleshooting on the Sample Preparation during Fused Deposition Modeling

Gibson, Ian , David W Rosen , Brent Stucker , Mahyar Khorasani , and David Rosen . 2021. Additive manufacturing technologies. Vol. 17: Springer.
Petrovic, Vojislav , Juan Vicente Haro Gonzalez , Olga Jordá Ferrando , Javier Delgado Gordillo , Jose Ramón Blasco Puchades , and Luis Portolés Griñan . 2011. Additive layered manufacturing: Sectors of industrial application shown through case studies. International Journal of Production Research 49 (4):1061–1079.
Chua, CK , SM Chou , and TS Wong . 1998. A study of the state-of-the-art rapid prototyping technologies. The International Journal of Advanced Manufacturing Technology 14 (2):146–152.
Jamieson, Ron , and Herbert Hacker . 1995. Direct slicing of CAD models for rapid prototyping. Rapid Prototyping Journal 1(2):4–12.
Upcraft, Steve , and Richard Fletcher . 2003. The rapid prototyping technologies. Assembly Automation 23(4):318–330.
Lee, Jian-Yuan , Jia An , and Chee Kai Chua . 2017. Fundamentals and applications of 3D printing for novel materials. Applied Materials Today 7:120–133.
Chua, C. K. and K. F. Leong . 2005. Rapid Prototyping: Principles and Applications in Manufacturing. John Willey, p. 400, 2005.
Dizon, John Ryan C , Alejandro H Espera Jr , Qiyi Chen , and Rigoberto C Advincula . 2018. Mechanical characterization of 3D-printed polymers. Additive Manufacturing 20:44–67.
Vaezi, Mohammad , Hermann Seitz , and Shoufeng Yang . 2013. A review on 3D micro-additive manufacturing technologies. The International Journal of Advanced Manufacturing Technology 67 (5):1721–1754.
DulieuBarton, JM , and MC Fulton . 2000. Mechanical properties of a typical stereolithography resin. Strain 36 (2):81–87.
Letcher, Todd , and Megan Waytashek . 2014. Material property testing of 3D-printed specimen in PLA on an entry-level 3D printer. Paper read at ASME International Mechanical Engineering Congress and Exposition.
Melenka, Garrett W , Benjamin KO Cheung , Jonathon S Schofield , Michael R Dawson , and Jason P Carey . 2016. Evaluation and prediction of the tensile properties of continuous fiber-reinforced 3D printed structures. Composite Structures 153:866–875.
De Leon, Al C , Qiyi Chen , Napolabel B Palaganas , Jerome O Palaganas , Jill Manapat , and Rigoberto C Advincula . 2016. High performance polymer nanocomposites for additive manufacturing applications. Reactive and Functional Polymers 103:141–155.
Jin, Yu-an , Hui Li , Yong He , and Jian-zhong Fu . 2015. Quantitative analysis of surface profile in fused deposition modelling. Additive Manufacturing 8:142–148.
Ultimaker , “https://support.ultimaker.com/hc/en-us/articles/360012113239-How-to-fix-warping,” [Online]. Available: https://support.ultimaker.com/hc/en-us/articles/360012113239-How-to-fix-warping
Ultimaker , “https://support.ultimaker.com/hc/en-us/articles/360012016280-How-to-fix-stringing,” [Online]. Available: https://support.ultimaker.com/hc/en-us/articles/360012016280-How-to-fix-

stringing
All3DP , “https://all3dp.com/2/3d-print-stringing-easy-ways-to-prevent-it/,” [Online]. Available: https://all3dp.com/2/3d-print-stringing-easy-ways-to-prevent-it/
Ultimaker , “https://support.ultimaker.com/hc/en-us/articles/360012112859-How-to-fix-under-extrusion,” [Online]. Available: https://support.ultimaker.com/hc/en-us/articles/360012112859-How-to-fix-under-extrusion
All3DP , “https://all3dp.com/2/under-extrusion-3d-printing-all-you-need-to-know/,” [Online]. Available: https://all3dp.com/2/under-extrusion-3d-printing-all-you-need-to-know/
ALL3DP , “https://all3dp.com/2/elephant-s-foot-3d-printing-problem-easy-fixes/,” [Online]. Available: https://all3dp.com/2/elephant-s-foot-3d-printing-problem-easy-fixes/

Hybrid Additive Manufacturing Technologies

Kumaran, M. & Senthilkumar, V. (2021). Experimental characterization of stainless steel 316L alloy fabricated with combined powder bed fusion and directed energy deposition. Welding in the World, 65(7), 1373–1388.
Kumaran, M. & Senthilkumar, V. (2021). Generative Design and Topology Optimization of Analysis and Repair Work of Industrial Robot Arm Manufactured Using Additive Manufacturing Technology. In IOP Conference Series: Materials Science and Engineering (Vol. 1012, No. 1, p. 012036). IOP Publishing.
Martin, N. , Hor, A. , Copin, E. , Lours, P. , & Ratsifandrihana, L. (2022). Correlation between microstructure heterogeneity and multi-scale mechanical behavior of hybrid LPBF-DED Inconel 625. Journal of Materials Processing Tech, 303:117542.
Cyr, E. , Asgari, H. , Shamsdini, S. , Purdy, M. , Hosseinkhani, K. , & Mohammadi, M. (2018). Fracture behaviour of additively manufactured MS1-H13 hybrid hard steels. Materials Letters, 212:174–177.
Müller, S. & Woizeschke, P. (2021). Feasibility of a laser powder bed fusion process for additive manufacturing of hybrid structures using aluminum-titanium powder-substrate pairings. Additive Manufacturing, 48:102377.
Li, P. , Gong, Y. , Xu, Y. , Qi, Y. , Sun, Y. , & Zhang, H. (2019). Inconel-steel functionally bimetal materials by hybrid directed energy deposition and thermal milling: Microstructure and mechanical properties. Archives of Civil and Mechanical Engineering, 19:820–831.
Liu, Z. , Ma, R. , Guojian , Wang, W. , & Liu, J. (2020). Laser additive manufacturing of bimetallic structure from Ti-6Al-4V to Ti-48Al-2Cr-2Nb via vanadium interlayer. Materials Letters, 263, 127210.
Thompson, S. M. , Bian, L. , Shamsaei, N. , & Yadollahi, A. (2015). An overview of direct laser deposition for additive manufacturing; Part I: Transport phenomena, modeling and diagnostics. Additive Manufacturing, 8, 36–62.
Saboori, A. , Aversa, A. , Marchese, G. , Biamino, S. , Lombardi, M. , & Fino, P. (2019). Application of directed energy deposition-based additive manufacturing in repair. Applied Sciences, 9(16), 3316.
Dilberoglu, U. M. , Gharehpapagh, B. , Yaman, U. , & Dolen, M. (2017). The role of additive manufacturing in the era of industry 4.0. Procedia Manufacturing, 11, 545–554.
Kumaran, M. , Senthilkumar, V. , Panicker, C. J. , & Shishir, R. (2021). Investigating the residual stress in additive manufacturing of combined process in powder bed fusion and directed energy deposition. Materials Today: Proceedings, 47, 4387–4390.
Kumaran, M. , Senthilkumar, V. , Panicke, C. J. , & Shishir, R. (2021). Investigating the residual stress in additive manufacturing of repair work by directed energy deposition process on SS316L hot rolled steel substrate. Materials Today: Proceedings, 47, 4475–4478.
Häfele, T. , Schneberger, J. H. , Kaspar, J. , Vielhaber, M. , & Griebsch, J. (2019). Hybrid additive manufacturing – Process chain correlations and impacts. Procedia CIRP, 84, 328–334.
Thompson, M. K. , Stolfi, A. , & Mischkot, M. (2016). Process chain modeling and selection in an additive manufacturing context. CIRP Journal of Manufacturing Science and Technology, 12, 25–34.
Lewandowski, J. J. , & Seifi, M. (2016). Metal additive manufacturing: a review of mechanical properties. Annual Review of Materials Research, 46, 151–186.

Bambach, M. , Sizova, I. , Sydow, B. , Hemes, S. , & Meiners, F. (2020). Hybrid manufacturing of components from Ti-6Al-4V by metal forming and wire-arc additive manufacturing. Journal of Materials Processing Technology, 282, 116689.

Yamazaki, T. (2016). Development of a hybrid multi-tasking machine tool: Integration of additive manufacturing technology with CNC machining. Procedia CIRP, 42, 81–86.

Dilberoglu, U. M. , Gharehpapagh, B. , Yaman, U. , & Dolen, M. (2021). Current trends and research opportunities in hybrid additive manufacturing. The International Journal of Advanced Manufacturing Technology, 113(3), 623–648.

Sefene, E. M. , Hailu, Y. M. , & Tsegaw, A. A. (2022). Metal hybrid additive manufacturing: State-of-the-art. Progress in Additive Manufacturing, 7(4), 737–749.

Kumaran, M. , Senthilkumar, V. , Panicker, C. T. , & Shishir, R. (2022). Investigating the microhardness values of SS316L of hybrid additive manufacturing and micromilling process. In Recent Advances in Materials and Modern Manufacturing (pp. 89–95). Springer, Singapore.

Kumaran, M. , Senthilkumar, V. , Sathies, T. , & Panicker, C. J. (2022). Effect of heat treatment on stainless steel 316L alloy sandwich structure fabricated using directed energy deposition and powder bed fusion. Materials Letters, 313, 131766.

Kumaran, M. , Senthilkumar, V. , Justus Panicker, C. T. , & Shishir, R. (2022). Concept design and analysis of multi-layer and multi-process piston of SS316L and AlSi10Mg by additive manufacturing. In Recent Advances in Materials and Modern Manufacturing (pp. 441–446). Springer, Singapore.

Kumaran, M. , & Senthilkumar, V. (2022). Influence of heat treatment on stainless steel 316L alloy manufactured by hybrid additive manufacturing using powder bed fusion and directed energy deposition. Metals and Materials International, 29, 1–18.

Kumaran, M. , Sathies, T. , Balaji, N. S. , Bharathiraja, G. , Mohan, S. , & Senthilkumar, V. (2022). Influence of heat treatment on stainless steel 316L alloy fabricated using directed energy deposition. Materials Today: Proceedings, 62, 5307–5310.

Kumaran, M. (2022). Experimental Investigations on Directed Energy Deposition Based Repair of Stainless Steel 316L Alloy Substrate Manufactured through Hot Rolled Steel and Powder Bed Fusion Process. Journal of Materials Engineering and Performance, 1–12. 10.1007/s11665-022-07513-w

Smart Manufacturing Using 4D Printing

N. Araújo , V. Pacheco , and L. Costa , Smart additive manufacturing: The path to the digital value chain, Technologies, 9 (2021), 88. 10.3390/technologies9040088

T. Phillips , J. Allison , C. Seepersad , and J. Beaman , Smart manufacturing in additive manufacturing, Smart Manufacturing, 2020 Elsevier Inc., 10.1016/B978-0-12-820028-5.00007-2

F. Aqlan and C. de Vries , Mariea Sargent, Andrew Valentine, using 3D printing to teach design and manufacturing concepts, Proceedings of the 2020 IISE Annual Conference L. Cromarty , R. Shirwaiker , P. Wang , eds.

https://3dprinting.com/what-is-3d-printing/-accessed on 01-08-2022 :11.57 am.

https://manufactur3dmag.com/3d-printing-applications/-accessed on 01-08-2022 :12.05 pm.

I. Paoletti and L. Ceccon , The evolution of 3D printing in AEC: From experimental to consolidated techniques, 10.5772/intechopen.79668

M. Pagac , J. Hajnys , Q.-P. Ma , L. Jancar , J. Jansa , P. Stefek and J. Mesicek , A review of vat photopolymerization technology: Materials, applications, challenges, and future trends of 3D printing, Polymers. 13 (2021), 598. 10.3390/polym13040598

W. Gao , Y. Zhang , D. Ramanujan , K. Ramani , Y. Chen , C. B. Williams , C. C. L. Wang , Y. C. Shin , S. Zhang , and P. D. Zavattieri , Comput. Aided Des. 69 (2015), 65.

J. C. Breger , C. Yoon , R. Xiao , H. R. Kwag , M. O. Wang , J. P. Fisher , … and D. H. Gracias , Self-folding thermo-magnetically responsive soft microgrippers, ACS Appl. Mater. & Interfaces. 7 (5) (2015), 3398–3405.

F. Momeni , X. Liu , and J. Ni F., A review of 4D printing, Mater. & Des. 122 (2017), 42–79.

E. Hawkes , B. An , N. M. Benbernou , H. Tanaka , S. Kim , E. D. Demaine , … and R. J. Wood , Programmable matter by folding, Proceedings of the National Academy of Sciences. 107 (28) (2010), 12441–12445.

S. E. Bakarich , R. Gorkin III , M. I. H. Panhuis , and G. M. Spinks , 4D Printing with mechanically robust, thermally actuating hydrogels, Macromol. Rapid Commun. 36 (12) (2015), 1211–1217.
S. Tibbits , C. McKnelly , C. Olguin , D. Dikovsky , and S. Hirsch , in: Proc. Of the 34th Annual Conference of the Association for Computer Aided Design in Architecture vol. 539, 2014.
B. An , and D. Rus , in: Presented at IEEE International Conference on Robotics and Automation, 2012. USA.
Y. Liu , W. Zhang , F. Zhang , X. Lan , J. Leng , S. Liu , X. Jia , C. Cotton , B. Sun , B. Gu , and T.-W. Chou , Compos. B. Eng.. 153 (2018), 233.
K. K. Shigetomi , H. Onoe , and S. Takeuchi , Han, PLoS ONE 12 (2012), 1.
https://www.sculpteo.com/en/3d-learning-hub/best-articles-about-3d-printing/4d-printing-technology/-accessed on 22-07-2022 :7.37 am.
W. Zhou , Z. Qiao , E. N. Zare , J. Huang , X. Zheng , X. Sun , M. Shao , H. Wang , X. Wang , D. Chen , J. Zheng , S. Fang , Y. M. Li , X. Zhang , L. Yang , P. Makvandi , and A. Wu , 4D-Printed dynamic materials in biomedical applications: Chemistry, challenges, and their future perspectives in the clinical sector, J. Med. Chem. 2020 (63) (2020), 8003−8024, 10.1021/acs.jmedchem.9b02115
F. Momeni , S. M. M. Hassani , N. X. Liu , and J. Ni , Mater. Des. 12 (2017), 42.
A. Ahmed , S. Arya , V. Gupta , H. Furukawa , A. Khosla , 4D printing: Fundamentals, materials, applications and challenges, Polymer. 228 (2021) (2021), 123926, 10.1016/j.polymer.2021.123926
F. Momeni , and J. Ni , Laws of 4D printing, Engineering. 6 (2020) (2020), 1035–1055, 10.1016/j.eng.2020.01.015
Z. Zhao , J. Wu , X. Mu , H. Chen , H. J. Qi , and D. Fang , Macromol. Rapid Commun. 13 (2017).
X. Kuang , D. J. Roach , J. Wu , C. M. Hamel , Z. Ding , T. Wang , M. L. Dunn , and H. J. Qi , Adv. Funct. Mater. 29 (2018), 1805290.
J. A. Lewis , J. E. Smay , J. Stuecker , J. Cesarano , and J. Am , Ceram. Soc. 12 (2010), 3599.
Q. Zhao , J. Sun , Q. Ling , and Q. Zhou , Langmuir 5 (2009) 3249] [J.P. Gong, Y. Katsuyama, T. Kurokawa, Y. Osada, Adv. Mater. 14 (2003), 1155.
M. C. Mulakkal , R. S. Trask , V. P. Ting , and A. M. Seddon , Mater. Des. 160 (2018), 108.
S. Erkeçoglu , A. D. Sezer , and S. Bucak , Smart drug deliv. Syst. 1 (2016).
M. D. Monzon , R. Paz , E. Pei , F. Ortega , L. A. Suarez , Z. Ortega , M. E. Aleman , T. Plucinski , and N. Clow , Int. J. Adv. Manuf. Technol. 89 (2017), 1827.
J. M. Pearce , Science 6100 (2012), 1303.
T. Campbell , S. Tibbits , and B. Garret , Sci. Am. 311 (2014), 60.
Y. Zhou , W. M. Huang , S. F. Kang , X. L. Wu , H. B. Lu , J. Fu , H. Cui , and J. Mech . Sci. Technol. 10 (2015), 4281.
S. Tibbits , in: Proc. 31st Annual Conference of ACADIA, 2011. Banff.
T. Raviv , and L. Striukova , Sci. Rep. 4 (2014), 7422.
S. Bauer , S. B. Gogonea , I. Graz , M. Kaltenbrunner , C. Keplinger , and R. Schwodiauer , Adv. Mater. 26 (2014), 149.
B. Gao , Q. Yang , X. Zhao , G. Jin , Y. Ma , and F. Xu , Trends Biotechnol. 34 (2016), 746.
J. Gosnell , T. Pietila , B. P. Samuel , H. K. N. Kurup , M. P. Haw , and J. J. Vettukattil , J. Digit. Imag. 6 (2016), 665.
P. He , J. Zhao , J. Zhang , B. Li , Z. Gou , M. Gou , and X. Li , Burns Trauma. 5 (2018), 1
Y. C. Li , Y. S. Zhang , A. Akpek , S. R. Shin , and A. Khademhosseini , Biofabrication. 9 (2016), 012001.
N. J. Castro , C. Meinert , P. Levett , and D. W. Hutmacher , Curr. Opin. Biomed. Eng. 2 (2017), 67.
D. A. Zopf , A. G. Mitsak , C. L. Flanagan , M. Wheeler , G. E. Green , S. Hollister , Otolaryngol. Head Neck Surg. 152 (2015), 57.
S. Miao , W. Zhu , N. J. Castro , M. Nowicki , X. Zhou , H. Cui , J. P. Fisher , and L. G. Zhang , Sci. Rep. 6 (2016), 27226.
C. Yang , X. Tian , T. Liu , Y. Cao , and D. Li , Rapid Prototyp. J. 1 (2017), 209–215.
S. H. Ahn , K. T. Lee , H. J. Kim , R. Wu , J. S. Kim , and S. H. Song , Int. J. Precis. Eng. Manuf. 4 (2012), 631.

A. O'Halloran , F. O'Malley , and P. McHugh , J. Appl. Phys. 7 (2008), 071101.
L. Justin , M. Amelia , and B. Christopher , in: Presented at 22nd Annual International Solid Freeform Fabrication Symposium, 2011. Austin, TX.
M. López-Valdeolivas , D. Liu , D. J. Broer , and C. Sánchez-Somolinos , Macromol. Rapid Commun. 5 (2018), 1700710.
C. Della Santina , R. K. Katzschmann , A. Biechi , D. Rus , in: Presented at IEEE International Conference on Soft Robotics, 2018, pp. 46–53. RoboSoft.
Q. Ge , C. K. Dunn , H. J. Qi , and M. L. Dunn , Active origami by 4D printing, Smart Mater. Struct. 9 (2014), 094007.
M. Röttger , T. Domenech , R. van der Weegen , A. Breuillac , R. Nicolaÿ , and L. Leibler , Science 356 (2017), 62.
Y. S. Zhang , K. Yue , J. Aleman , K. Mollazadeh-Moghaddam , S. M. Bakht , J. Yang , W. Jia , V. Dell'Erba , P. Assawes , S. R. Shin , M. R. Dokmeci , R. Oklu , and A. Khademhosseini , Ann. Biomed. Eng. 1 (2017), 148.
P. Cordier , F. Tournilhac , C. Soulie-Ziakovic , and L. Leibler , Nature. 451 (2008), 977.
S. Ramesh , C. Usha , N. K. Naulakha , C. R. Adithyakumar , and M. Reddy , Mater. Sci. Eng. 1 (2018), 012123.
S. V. Huo , Compos. Struct. 210 (2019), 869.
A. Haleem , M. Javaid , R. P. Singh , and R. Suman , Significant roles of 4D printing using smart materials in the field of manufacturing, Advanced Industrial and Engineering Polymer Research.
S. K. Leist , and J. Zhou , Current status of 4D printing technology and the potential of light-reactive smart materials as 4D printable materials, Virtual Phys. Prototyp. 11 (4) (2016), 249–262.
S. K. Sinha , Additive manufacturing (AM) of medical devices and scaffolds for tissue engineering based on 3D and 4D printing, in: 3D and 4D Printing of Polymer Nanocomposite Materials, Elsevier, 2020, pp. 119–160.
K. Deshmukh , M. T. Houkan , M. A. AlMaadeed , and K. K. Sadasivuni , Introduction to 3D and 4D printing technology: State of the art and recent trends, 3D and 4D rint. Polym. Nanocomp. Mater. (2020), 1–24.
M. Javaid , and A. Haleem , Exploring smart material applications for COVID-19 pandemic using 4D printing technology, J. Indust. Integrat. Manag. 5 (4) (2020), 481–494.
Y. S. Lui , W. T. Sow , L. P. Tan , Y. Wu , Y. Lai , and H. Li , 4D Printing and stimuli responsive materials in biomedical aspects, Acta Biomater. 92 (2019), 19–36.
C. Lin , L. Liu , Y. Liu , and J. Leng , 4D printing of bioinspired absorbable left atrial appendage occluders: A proof-of-concept study, ACS Appl. Mater. Interfaces. 13 (11) (2021), 12668–12678.
G. Sossou , F. Demoly , H. Belkebir , H. J. Qi , S. Gomes , and G. Montavon , Design for 4D printing: A voxel-based modeling and simulation of smart materials, Mater. Des. 175 (2019), 107798.
A. Nishiguchi , H. Zhang , S. Schweizerhof , M. F. Schulte , A. Mourran , and M. Mooller , 4D printing of a light-driven soft actuator with programmed printing density, ACS Appl. Mater. Interfaces 12 (10) (2020), 12176–12185.
J. Lee , H. C. Kim , J. W. Choi , and I. H. Lee , A review on 3D printed smart devices for 4D printing, Int. J. Prec. Eng. Manuf. Green Technol. 4 (3) (2017), 373–383.
F. B. Coulter , and A. Ianakiev , 4D printing inflatable silicone structures, 3D Print. Addit. Manuf. 2 (3) (2015) 140–144.
M. H. Ali , A. Abilgaziyev , and D. Adair , 4D Printing: A critical review of current developments, and future prospects, Int. J. Adv. Manuf. Technol. 105 (1) (2019), 701–717.
Y. Y. C. Choong , S. Maleksaeedi , H. Eng , J. Wei , and P. C. Su , 4D Printing of high-performance shape memory polymer using stereolithography, Mater. Des. 126 (2017), 219–225.
A. Haleem , and M. Javaid , Expected role of four-dimensional (4D) CT and four dimensional (4D) MRI for the manufacturing of smart orthopaedics implants using 4D printing, J. Clin. Orthopaed. Trauma. 10 (2019), S234–S235.
Y. Jiang , J. Leng , and J. Zhang , A high-efficiency way to improve the shape memory property of 4D-printed polyurethane/polylactide composite by forming in situ microfibers during extrusion-based additive manufacturing, Add. Manuf. 38 (2021), 101718.

S. V. Hoa , Factors affecting the properties of composites made by 4D printing (moldless composites manufacturing), Adv. Manuf. Polym. Compos. Sci. 3 (3) (2017), 101–109.

S. Y. Hann , H. Cui , M. Nowicki , and L. G. Zhang , 4D Printing soft robotics for biomedical applications, Add. Manuf. 36 (2020), 101567.

M. P. Caputo , A. E. Berkowitz , A. Armstrong , P. Müllner , and C. V. Solomon , 4D Printing of net shape parts made from Ni-Mn-Ga magnetic shape-memory alloys, Add. Manuf. 21 (2018), 579–588.

D. Grinberg , S. Siddique , M. Q. Le , R. Liang , J. F. Capsal , and P. J. Cottinet , 4D Printing based piezoelectric composite for medical applications, J. Polym. Sci. B Polym. Phys. 57 (2) (2019), 109–115.

H. Ding , X. Zhang , Y. Liu , and S. Ramakrishna , Review of mechanisms and deformation behaviors in 4D printing, Int. J. Adv. Manuf. Technol. 105 (11) (2019), 4633–4649.

Y. Zhang , Q. Wang , S. Yi , Z. Lin , C. Wang , Z. Chen , and L. Jiang , 4D Printing of magnetoactive soft materials for on-demand magnetic actuation transformation, ACS Appl. Mater. Interfaces. 13 (3) (2021), 4174–4184.

A. Haleem , M. Javaid , and R. Vaishya , 4D printing and its applications in orthopaedics, J. Clin. Orthopaed. Trauma. 9 (3) (2018), 275.

S. Chung , S. E. Song , and Y. T. Cho , Effective software solutions for 4D printing: A review and proposal, Int. J. Prec. Eng. Manuf. Green Technol. 4 (3) (2017), 359–371.

M. Zarek , N. Mansour , S. Shapira , and D. Cohn , 4D printing of shape memory based personalised endoluminal medical devices, Macromol. Rapid Commun. 38 (2) (2017), 1600628.

S. Saska , L. Pilatti , A. Blay , and J. A. Shibli , Bioresorbable polymers: advanced materials and 4D printing for tissue engineering, Polymers. 13 (4) (2021), 563.

Q. Ge , C. K. Dunn , H. J. Qi , and M. L. Dunn , Active origami by 4D printing, Smart Mater. Struct. 23 (9) (2014), 094007.

S. Valvez , P. N. Reis , L. Susmel , and F. Berto , Fused filament fabrication-4D-printed shape memory polymers: A review, Polymers. 13 (5) (2021), 701.

R. Ashima , A. Haleem , S. Bahl , M. Javaid , S. K. Mahla , and S. Singh , Automation and manufacturing of smart materials in additive manufacturing technologies using internet of things towards the adoption of industry 4.0, Mater. Today: Proc. (2021).

K. Ahmed , M. N. I. Shiblee , A. Khosla , L. Nagahara , T. Thundat , and H. Furukawa , Recent progresses in 4D printing of gel materials, J. Electrochem. Soc. 167 (3) (2020), 037563.

A. Chadha , M. I. Haq , A. Raina , R. R. Singh , N. B. Penumarti , and M. S. Bishnoi , Effect of fused deposition modelling process parameters on mechanical properties of 3D printed parts, World J. Eng. 16 (4) (2019), 550–559.

J. Wang , Z. Wang , Z. Song , L. Ren , Q. Liu , and L. Ren , Biomimetic shapeecolor double-responsive 4D printing, Adv. Mater. Technol. 4 (9) (2019), 1900293.

R. Aziz , M. I. Haq , and A. Raina , Effect of surface texturing on friction behavior of 3D printed polylactic acid (PLA), Polym. Test. 85 (2020), 106434.

P. R. Reddy , and P. A. Devi , Review on the advancements of additive manufacturing-4D and 5D printing, Int. J. Mech. Prod. Eng. Res. Dev. 8 (4) (2018), 397–402.

Y. Zhang , L. Huang , H. Song , C. Ni , J. Wu , Q. Zhao , and T. Xie , 4D printing of a digital shape memory polymer with tunable high performance, ACS Appl. Mater. Interfaces. 11 (35) (2019), 32408–32413.

H. Hassanin , A. Abena , M. A. Elsayed , and K. Essa , 4D printing of NiTi auxetic structure with improved ballistic performance, Micromachines. 11 (8) (2020), 745.

A. Haleem , and M. Javaid , expected role of four-dimensional (4D) CT and four-dimensional (4D) MRI for the manufacturing of smart orthopaedics implants using 4D printing, J. Clin. Orthopaed. Trauma. 10 (2019), S234–S235.

A. Hassan , Alshahrani, Review of 4D printing materials and reinforced composites: Behaviours, applications and challenges, J. Sci.: Adv. Mater. Devices. 6 (2021), 167–185.

D.-G. Shin , T.-H. Kim , and D.-E. Kim , Review of 4D printing materials and their properties, International Journal of Precision Engineering and Manufacturing-Green Technology, Vol. 4, No. 3, pp. 349–357.

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S. Ramesh , S. Kiran Reddy , C. Usha , N. K. Naulakha , C. R. Adithyakumar , and M. Lohith Kumar Reddy , Advancements in the research of 4D printing-A review, in IOP Conference Series: Materials Science and Engineering, vol. 376, no. 1, Jun. 2018, doi: 10.1088/1757-899X/376/1/012123

X. Li , J. Shang , and Z. Wang , Intelligent materials: A review of applications in 4D printing, Assem Autom, vol. 37, no. 2, pp. 170–185, 2017, doi: 10.1108/AA-11-2015-093

E. Pei , 4D printing: Dawn of an emerging technology cycle, Assem Autom, vol. 34, no. 4. Emerald Group Holdings Ltd., pp. 310–314, Sep. 09, 2014. doi: 10.1108/AA-07-2014-062

R. El-Dabaa and I. Salem , 4D printing of wooden actuators: encoding FDM wooden filaments for architectural responsive skins, Open House Int, vol. 46, no. 3, pp. 376–390, Jan. 2021, doi: 10.1108/OHI-02-2021-0028

I. T. Garces and C. Ayranci , Advances in additive manufacturing of shape memory polymer composites, Rapid Prototyp J, vol. 27, no. 2, pp. 379–398, Jan. 2021, doi: 10.1108/RPJ-07-2020-0174

E. Pei , G. H. Loh , D. Harrison , H. de Amorim Almeida , M. D. M. Verona , and R. Paz , A study of 4D printing and functionally graded additive manufacturing, Assem Autom, vol. 37, no. 2, pp. 147–153, 2017, doi: 10.1108/AA-01-2017-012

E. Pei , 4D printing - Revolution or fad?, Assem Autom, vol. 34, no. 2, pp. 123–127, 2014, doi: 10.1108/AA-02-2014-014

H. Yi , 4D-printed parametric façade in architecture: prototyping a self-shaping skin using programmable two-way shape memory composite (TWSMC), Eng. Constr. Archit. Manag., vol. ahead-of-print, no. ahead-of-print, Jan. 2021, doi: 10.1108/ECAM-05-2021-0428

A. Nespoli , N. Bennato , E. Bassani , and F. Passaretti , Use of 4D-printing and shape memory alloys to fabricate customized metal jewels with functional properties, Rapid Prototyp J, vol. ahead-of-print, no. ahead-of-print, Jan. 2021, doi: 10.1108/RPJ-06-2021-0156

J. Carrell , G. Gruss , and E. Gomez , Four-dimensional printing using fused-deposition modeling: a review, Rapid Prototyping J, vol. 26, no. 5. Emerald Group Holdings Ltd., pp. 855–869, May 19, 2020. doi: 10.1108/RPJ-12-2018-0305

S. S. Mohol and V. Sharma , Functional applications of 4D printing: a review, Rapid Prototyp J, vol. 27, no. 8, pp. 1501–1522, Jan. 2021, doi: 10.1108/RPJ-10-2020-0240

J. Choi , O. C. Kwon , W. Jo , H. J. Lee , and M. W. Moon , 4D printing technology: A review, 3D Printing and Additive Manufacturing, vol. 2, no. 4. Mary Ann Liebert Inc., pp. 159–167, Dec. 01, 2015. doi: 10.1089/3dp.2015.0039

A. Haleem , M. Javaid , R. P. Singh , and R. Suman , Significant roles of 4D printing using smart materials in the field of manufacturing, Advanced Industrial and Engineering Polymer Research, vol. 4, no. 4. KeAi Communications Co., pp. 301–311, Oct. 01, 2021. doi: 10.1016/j.aiepr.2021.05.001

A. Ahmed , S. Arya , V. Gupta , H. Furukawa , and A. Khosla , 4D printing: Fundamentals, materials, applications and challenges, Polymer, vol. 228. Elsevier Ltd, Jul. 16, 2021. doi: 10.1016/j.polymer.2021.123926

H. A. Alshahrani , Review of 4D printing materials and reinforced composites: Behaviors, applications and challenges, J Sci: Adv Mater Devices, vol. 6, no. 2. Elsevier B.V., pp. 167–185, Jun. 01, 2021. doi: 10.1016/j.jsamd.2021.03.006

X. Kuang *et al.* , REVIEW www.afm-journal.de Advances in 4D Printing: Materials and Applications, 2018, doi: 10.1002/adfm.afdm201805290

Z. X. Khoo *et al.* , 3D printing of smart materials: A review on recent progresses in 4D printing, Virtual Phys Prototyp, vol. 10, no. 3, pp. 103–122, Jul. 2015, doi: 10.1080/17452759.2015.1097054

K. R. Ryan , M. P. Down , and C. E. Banks , Future of additive manufacturing: Overview of 4D and 3D printed smart and advanced materials and their applications, Chem Eng J, vol. 403. Elsevier B.V., Jan. 01, 2021. doi: 10.1016/j.cej.2020.126162

Q. Zhang *et al.* , Origami and kirigami inspired self-folding for programming three-dimensional shape shifting of polymer sheets with light, Extreme Mech Lett, vol. 11, pp. 111–120, Feb. 2017,

doi: 10.1016/j.eml.2016.08.004
Z. Zhang , K. G. Demir , and G. X. Gu , Developments in 4D-printing: a review on current smart materials, technologies, and applications, Int J Smart Nano Mater, vol. 10, no. 3, pp. 205–224, Jul. 2019, doi: 10.1080/19475411.2019.1591541
K. K. Westbrook *et al.* , Two-way reversible shape memory effects in a free-standing polymer composite, Smart Mater Struct, vol. 20, no. 6, Jun. 2011, doi: 10.1088/0964-1726/20/6/065010
S. Erkeçoglu , A. D. Sezer , and S. Bucak , Smart Delivery Systems with Shape Memory and Self-Folding Polymers, in Smart Drug Deliv Syst, InTech, 2016. doi: 10.5772/62199
S. Joshi *et al.* , 4D printing of materials for the future: Opportunities and challenges, Appl Mater Today, vol. 18, Mar. 2020, doi: 10.1016/j.apmt.2019.100490
D. Kokkinis , M. Schaffner , and A. R. Studart , Multimaterial magnetically assisted 3D printing of composite materials, Nat Commun, vol. 6, Oct. 2015, doi: 10.1038/ncomms9643
Q. Ge , A. H. Sakhaei , H. Lee , C. K. Dunn , N. X. Fang , and M. L. Dunn , Multimaterial 4D Printing with Tailorable Shape Memory Polymers, Sci Rep, vol. 6, Aug. 2016, doi: 10.1038/srep31110
A. Rayate and P. K. Jain , A Review on 4D Printing Material Composites and Their Applications, 2018. [Online]. Available: www.sciencedirect.comwww.materialstoday.com/proceedings2214-7853
M. Bodaghi , A. R. Damanpack , and W. H. Liao , Adaptive metamaterials by functionally graded 4D printing, Mater Des, vol. 135, pp. 26–36, Dec. 2017, doi: 10.1016/j.matdes.2017.08.069
M. Zarek , N. Mansour , S. Shapira , and D. Cohn , 4D Printing of Shape Memory-Based Personalized Endoluminal Medical Devices, Macromol Rapid Commun, vol. 38, no. 2, Jan. 2017, doi: 10.1002/marc.201600628
S. Miao *et al.* , 4D printing smart biomedical scaffolds with novel soybean oil epoxidized acrylate, Sci Rep, vol. 6, Jun. 2016, doi: 10.1038/srep27226

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Khan, U. , & Haleem, A. (2015). Improving to the smart organization: An integrated ISM and fuzzy-MICMAC modelling of barriers. Journal of Manufacturing Technology Management.
Bitsch, G. , & Schweitzer, F. (2022). Selection of optimal machine learning algorithm for autonomous guided vehicle's control in a smart manufacturing environment. Procedia CIRP, 107, 1409–1414.
Luthra, S. , Kumar, V. , Kumar, S. , & Haleem, A. (2011). Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: An Indian perspective. Journal of Industrial Engineering and Management (JIEM), 4(2), 231–257.
Cronin, M. C. , Awasthi, M. A. , Conway, M. A. , O'Riordan, D. , & Walsh, J. (2020). Design and development of a material handling system for an autonomous intelligent vehicle for flexible manufacturing. Procedia Manufacturing, 51, 493–500.
Poduval, P. S. , & Pramod, V. R. (2015). Interpretive structural modeling (ISM) and its application in analyzing factors inhibiting implementation of total productive maintenance (TPM). International Journal of Quality & Reliability Management, 32(3), 308–331.
Prasanna, M. , & Vinodh, S. (2013). Lean Six Sigma in SMEs: An exploration through literature review. Journal of Engineering, Design, and Technology, 11(3), 224–250.
Kahveci, S. , Alkan, B. , Ahmad, M. , & Harrison, R. (2022). An end-to-end big data analytics platform for IoT-enabled smart factories: A case study of battery module assembly system for electric vehicles. Journal of Manufacturing Systems, 63, 214–223.
Lin, J. , Xiao, B. , Zhang, H. , Yang, X. , & Zhao, P. (2021). A novel underfill-SOC based charging pricing for electric vehicles in smart grid. Sustainable Energy, Grids and Networks, 28, 100533.
Nguyen, M. T. , Truong, L. H. , Tran, T. T. , & Chien, C. F. (2020). Artificial intelligence-based data processing algorithm for video surveillance to empower industry 3.5. Computers & Industrial Engineering, 148, 106671.
Kumar, A. G. , Anmol, M. , & Akhil, V. S. (2015). A strategy to enhance electric vehicle penetration level in India. Procedia Technology, 21, 552–559.

Yadav, G. , & Desai, T. N. (2017). Analyzing lean six sigma enablers: A hybrid ISM-fuzzy MICMAC approach. The TQM Journal.
Wu, W. S. , Yang, C. F. , Chang, J. C. , Château, P. A. , & Chang, Y. C. (2015). Risk assessment by integrating interpretive structural modeling and Bayesian network, case of offshore pipeline project. Reliability Engineering & System Safety, 142, 515–524.
Yadav, G. , Mangla, S. K. , Luthra, S. , & Rai, D. P. (2019). Developing a sustainable smart city framework for developing economies: An Indian context. Sustainable Cities and Society, 47, 101462.
Pansare, R. , Yadav, G. , & Nagare, M. R. (2022). Development of a structural framework to improve reconfigurable manufacturing system adoption in the manufacturing industry. International Journal of Computer Integrated Manufacturing, 1–32. 10.1080/0951192X.2022.2090604
Samantra, C. , Datta, S. , Mahapatra, S. S. , & Debata, B. R. (2016). Interpretive structural modeling of critical risk factors in software engineering project. Benchmarking: An International Journal.
Tripathy, S. , Sahu, S. , & Ray, P. K. (2013). Interpretive structural modelling for critical success factors of R&D performance in Indian manufacturing firms. Journal of Modelling in Management.
Valmohammadi, C. , & Dashti, S. (2016). Using interpretive structural modeling and fuzzy analytical process to identify and prioritize the interactive barriers of e-commerce implementation. Information & Management, 53(2), 157–168.
Yadav, N. , & Sagar, M. (2015). Modeling strategic performance management of automobile manufacturing enterprises: An Indian context. Journal of Modelling in Management.
Zargun, S. , & Al-Ashaab, A. (2014). Critical success factors for lean manufacturing: A systematic literature review an international comparison between developing and developed countries. Advanced Materials Research, 845, 668–681.
Pansare, R. , & Yadav, G. (2022). Repurposing production operations during COVID-19 pandemic by integrating Industry 4.0 and reconfigurable manufacturing practices: an emerging economy perspective. Operations Management Research, 1–20.
Psomas, E. L. (2013). The effectiveness of the ISO 9001 quality management system in service companies. Total Quality Management & Business Excellence, 24(7–8), 769–781.
Psychogios, A. G. , Atanasovski, J. , & Tsironis, L. K. (2012). Lean Six Sigma in a service context: A multifactor application approach in the telecommunications industry. International Journal of Quality & Reliability Management.
Rajaprasad, S. V. S. , & Chalapathi, P. V. (2015). Factors influencing implementation of OHSAS 18001 in Indian construction organizations: An interpretive structural modeling approach. Safety and health at work, 6(3), 200–205.
Sahu, A. R. , Shrivastava, R. R. , & Shrivastava, R. L. (2013). Critical success factors for sustainable improvement in technical education excellence: A literature review. The TQM journal.

Safety Management with Application of Internet of Things, Artificial Intelligence, and Machine Learning for Industry 4.0 Environment

H. Kagermann , W. Wahlster and J. Helbig , Recommendations for Implementing the Strategic Iniciative Industrie 4.0, Final Report of the Industrie 4.0 Working Group, Acien-National Acadamy of Science and Engineering, 2013.
K. Jilcha and D. Kitaw , Industrial occupational safety and health innovation for sustainable development, Engineering Science and Technology, an International Journal, vol. 20, no. 1, pp. 372–380, 2017.
F. Qian , W. Zhong and W. Du , Smart process manufacturing—perspective fundamental theories and key technologies for smart and optimal manufacturing in the process industry, Engineering Journal, vol. 3, no. 2, pp. 154–160, 2017.
F. Brocal , C. Gonzalez , D. Komljenovic , P. F. Katina and M. A. Sebastian , Emerging Risk Management in Industry 4.0: An Approach to Improve Organizational and Human Performance in the Complex Systems, Complexity, 2019.

M. Beetz , G. Bartels , A. Albu-Schaffer , F. Balint-Benczedi , R. Belder and D. Bebler , Robotic agents capable of natural and safe physical interaction with human co-workers, in *IEEE International Conference on Intelligent Robots and Systems* , Hamburg, Germany, 2015.

B. Waschneck , T. Altenmuller , T. T. Bauernhansl and A. Kyek , Production scheduling in complex job shops from an industrie 4.0 perspective: a review and challenges in the semiconductor industry, in *Centre for European Union Resarch Workshop Proceeding* , 2017.

C. Block , S. Freith , N. Kreggenfeld , F. Morlock , C. Prinz , D. Kriemeier and B. B. Kuhlenkhotter , Industry 4.0 as a Socio-technical Area of Tension Holistic View of Technology, Organization and Personnel, ZWF Journal of Economic Factory Management, vol. 110, no. 10, pp. 657–660, 2015.

A. Rojko , Industry 4.0 concept: background and overview, International Journal of Interactive Mobile Technologies, vol. 11, no. 5, pp. 77–90, 2017.

J. Qin , Y. Liu and R. Grosvenor , A categorical framework of manufacturing for industry 4.0 and beyond, Proceedia CIRP, vol. 52, no. 1, pp. 173–178, 2016.

J. Kaivo-Oja , P. Virtanen , H. Jalonen and J. Stenvall , The effects of the internet of things and big data to organizations and their knowledge management practices in Knowlegde Management in Organizations, in Lecture Notes in Business Information Processing, vol. 224, Slovenia, Ed., Springer, 2015, pp. 495–513.

D. D. Podgorski , K. Majchrzycka , A. Dąbrowska , G. Gralewicz and M. Okrasa , Towards a conceptual framework of OSH risk management in smart working environments based on smart PPE, ambient intelligence and the Internet of Things technologies, International Journal of Occupational Safety and Ergonomics, vol. 23, no. 1, pp. 1–20, 2017.

F. Fernandez and M. Perez , Analysis and Modeling of New and Emerging Occupational Risks in the Context of Advanced Manufacturing Processes, Procedia Engineering, vol. 100, no. 1, pp. 1050–1059, 2015.

D. Kuschnerus , A. Bilgic , F. Bruns and T. Musch , A hierarchical domain model for safety-critical cyber-physical systems in process automation, in *IEEE International Conference on Industrial Informatics* , Cambridge, 2015.

C. E. Siemieniuch , M. A. Sinclair and M. J. C. Henshaw , Global drivers, sustainable manufacturing and systems ergonomics, Applied Ergonomics, vol. 51, no. 1, pp. 104–119, 2015.

S. Mattson , J. Partini and A. Berglund , Evaluating Four Devices that Present Operator Emotions in Real-time, Procedia CIRP, vol. 50, no. 1, pp. 524–528, 2016.

J. A. Palazon , J. Gozalvez , J. L. Maestre and J. R. Gisbert , Wireless solutions for improving health and safety working conditions in industrial environments, in IEEE 15th International Conference on eHealth Networking, Applications and Services Healthcom," Boston, 2013.

J. R. Gisbert , C. Palau , M. Uriarte , G. Prieto , J. A. Palazon , M. Esteve , O. Lopez , J. Correas , M. C. Lucas Estan , P. Gimenez , A. Moyano , L. Collantes , J. Gozalvez , B. Molina , O. Lazaro and A. Gonzalez , Integrated system for control and monitoring industrial wireless networks for labor risk prevention, Journal of Network and Computer Applications, vol. 39, no. 1, pp. 233–252, 2014.

G. W. Vogl , B. A. Weiss and M. Helu , A review of diagnostic and prognostic capabilities and best practices for manufacturing, Journal of Intelligent Manufacturing, vol. 25, no. 1, pp. 1–17, 2016.

I. Bucker , M. Hermann , T. Pentek and B. Otto , Towards a methodology for Industries 4.0 transformation, Lecture Notes Business Information Processing, vol. 255, pp. 209–221, 2017.

D. Kiel , C. Arnold , M. Collisi and K. Voigt , The impact of the industriala internet of things on established business models, *25th International Assocaition for Management of Technology Conference* , 2016.

M. Reuter , Q. Henning , M. Wannoffel , D. Kreimeier , J. Klippert , P. Pawlicki and B. Kuhlenkotter , Learning Factories' Trainings as an Enabler of Proactive Workers' Participation Regarding Industrie 4.0, Procedia Manufacturing, vol. 9, no. 1, pp. 354–360, 2017.

E. MacEachen , A. Kosny , C. Stahl , F. O'Hagen , L. Redgrift , S. Sanford , C. Carrasco , E. Tompa and Q. Mahood , Systematic review of qualitative literature on occupational health and safety legislation and regulatory enforcement planning and implementation, Jorunal of Work, Environment & Health, vol. 42, no. 1, pp. 3–16, 2016.

R. Burke , C. Cooper and S. Clarke , Occupational Health and Safety, Gower, p. 392, 2011.

U. T. Schwarz , H. Hasson and S. Tafvelin , Leadership training as an occupational health intervention: Improved safety and sustained productivity, Safety Science, vol. 81, no. 1, pp.

35–45, 2016.
F. Brocal and M. Sebastain , Identification and Analysis of Advanced Manufacturing Processes Susceptible of Generating New and Emerging Occupational Risks, Procedia Engineering, vol. 132, no. 1, pp. 887–894, 2015.
T. Niesen , C. Houy , P. Fettke and P. Loss , Towards an integratuve big data analysis framework for data-driven risk management in industry4.0, in *Proceedings of the Annual Hawaii International Conference on System Sciences* , Koloa, Hawaii, 2016.
M. Malinowski , P. Beling , Y. Haimes , A. Laviers , J. Marvel and B. Weiss , System iSystem interdependency modeling in the design of prognostic and health management systems in smart manufatcuring, in *Proceedings of the Annual Conference of the Prognostics and Health Management Society* , San Diego, 2015.
A. P. Pacchini , W. C. Lucato , F. Facchini and G. Mummolo , The degree of readiness for the implementation of Industry 4.0, Computers in Industry, vol. 113, no. 1, pp. 103–125, 2019.
G. Zhen , T. Wanyama , I. Singh , A. Gadhrri and R. Schmidt , From Industry 4.0 to Robotics 4.0- A Conceptual Framework for Collaborative and Intelligent Robotic System, in *International Conference Interdisciplinarity in Engineering* , Romania, 2020.
S. Lass and N. Gronau , A factory operating system for extending existing factories to Industry 4.0, Computers in Industry, vol. 115, no. 1, pp. 103–128, 2020.
A. Napolene , M. Macchi and A. Pozzetti , A review on the characteristics of cyber-physical systems for the future smart factories, Journal of Manufacturing Systems, vol. 54, no. 1, pp. 305–335, 2020.
K. Adikaram and C. Nawarathna , Businees sector preparedness in disaster management: Case study with businesses in southern Sri Lanka in both aspects of natural and technological disasters, in *International Confernence on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction* , Bangkok, 2017.
V. E. Guaman , B. Muschard , M. Gerolamo , H. Khol and H. Rozenfeld , Characteristics and Skills of Leaderships in Context of Industry 4.0, in *Global Conference on Sustainable Manufacturing* , Shanghai, China, 2020.
W. Akram , M. Jain and C. Hemalatha , Design of a Smart Safety Device for Women using IoT, in *International Conference on Recent Trends in Advanced Computing* , chennai, India, 2019.
C. L. Niemeyer , I. Gehrke , K. Muller , D. Kusters and T. Gries , Getting Small Medium Enterprsies started on Industry 4.0 using retrofitting solutions, in *Conference on learning Factories* , Garz, Austria, 2020.
G. Beier , A. Ullrich , S. Niehoff , M. ReiBig and M. Habich , Industry4.0: How it is defined from a sociotechnical prespective and how much sustainability it includes- A literature Review, Journal of Cleaner Production, vol. 259, no. 1, pp. 120–156, 2020.
S. Fareri , G. Fantoni , F. Chiarello , E. Coli and A. Binda , Estimating Industry 4.0 impact on job profiles and skills using text mining, Computer in Industry, vol. 118, no. 1, pp. 103–222, 2020.
B. Chunguang , P. Dallasega , G. Orzes and J. Sarkis , Industry 4.0 technologies assessment: A sustainability prespective, International Journal of Production Economics, vol. 229, no. 1, 2020.
A. Angelopoulou , K. Mykoniatis and N. Boyapati , Industry 4.0: The use of simulation for human reliabilty assessment, in *International Conference on Industry 4.0 and Smart Manufacturing* , Rende, Italy, 2019.
S. K. Backhaus and D. Nadarajah , Investigating the Realtionship between Industry 4.0 and Productivity: A conceptual Framework for Malaysian Manufatcuring Firms, in *Information Systems International Conference* , Hyderabad, India, 2019.
S. Aheleroff , X. Xun , L. Yaqian , M. Aristizabal , J. Velasquez , J. Benjamin and Y. Valencia , IoT-enabled smart appliances under industry 4.0: A case study, Advanced Engineering Informatics, vol. 43, no. 1, pp. 1010–1043, 2020.
J. Weking , M. Stocker , M. Kowalkiewicz , M. Boham and H. Krcmar , Leveraging Industry 4.0- A business model pattern framework, International Journal of Production Economics, vol. 225, no. 1, pp. 1075–1088, 2020.
M. Hirman , A. Benesova , F. Steiner and J. Tupa , Project Management during the Industry 4.0 Implementation with Risk Factor Analysis, in *International Conference in Flexible Automation and Intelligent Manufacturing* , Limerick, Ireland, 2019.
V. Alcacer and V. Machado , Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems, Engineering Science and Technology an International Journal, vol.

22, no. 1, pp. 899–919, 2019.
J. Y. Won and M. Park , Smart fatcory adoption in small and medium-sized enterprises: Empirical evidence of manufatcuring industry in korea, Technological Forecasting & Social Change, vol. 157, no. 1, pp. 1201–1217, 2020.
S. S. Kamble , A. Gunasekaran and S. A. Gawankar , Sustainable Industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives, Process Safety and Environmental Protection, vol. 117, pp. 408–425, 2018.
G. Buchi , M. Cugno and R. Castagnoli , Smart factory performance and Industry 4.0, Technological Forecasting & Social Change, vol. 150, no. 1, 2020.
P. Osterrieder , L. Budde and T. Friedli , The smart factory as a key construct of industry 4.0: A systematic literature, International Journal of Production Economics, vol. 122, no. 1, pp. 219–222, 2020.
T. Aven , The risk concept-historical and recent development trends, Reliability Engineering & System Safety, vol. 99, pp. 33–44, 2012.
ISO-31000:2018 , Risk management–guidelines, in *International Organization for Standardization (ISO)* , Geneva, 2018.
ISO-45001:2018 , Occupational health and safety management systems-Requirements with guidance for use, in *International Organization for Standardization (ISO)* , Geneva, 2018.
ISO/NP-31050 , Guidance for managing emerging risks to enhance resilience, in *International Organization for Standardization (ISO)* , Geneva, 2019.
A. Badri , B. B. Trudel and A. S. Souissi , Occupational health and safety in the industry 4.0 era: A cause for major concern?, Safety Science, vol. 109, pp. 403–411, 2018.
T. Stock and G. Seliger , Opportunities of sustainable manufacturing in industry 4.0, Procedia CIRP, vol. 40, pp. 536–541, 2016.
B. J. V. Holland , R. Soer , M. R. D. Boer , M. F. Reneman and S. Brouwer , Preventive occupational health interventions in the meat processing industry in upper-middle and high-income countries: a systematic review on their effectiveness, International Journal of Architecture, Occupatational & Environmental Health, vol. 88, no. 4, pp. 389–402, 2015.
S. Simons , P. Abe and S. Neser , Learning in the AutFab – The fully automated Industrie 4.0. Learning factory of the University of Applied Sciences Darmstadt, Procedia Manufacturing, vol. 9, pp. 81–88, 2017.
Kip Hanson/ Protolabs , Data, Digital Threads, and Industry 4.0, Manufaqcturing tommorrow, an online Trade Magazine - Industry 4.0 Advanced Manufacturing and Factory Automation, 18/08/2016.
S. Percy , Artificial Intelligence: The Role of Evolution in Decision-Making, 7wdata, 23 MARCH 2017.
D. Komljenovic , G. Loiselle and M. Kumral , Organization: a new focus on mine safety improvement in a complex operational and business environment, International Journal of Mining Science and Technology, vol. 27, no. 4, pp. 617–625, 2017.
G. K. Badhotiya , V. P. Sharma , S. Prakash , V. Kalluri and R. Singh , Investigation and assessment of blockchain technology adoption in the pharmaceutical supply chain, Materials Today: Proceedings, vol. 46, pp. 10776–10780, 2021.

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Al Mustanyir, S. (2023). Government healthcare financing and dwindling oil prices: Any alternatives for OPEC countries?. Cogent Economics & Finance, 11(1), 2166733.
Atkinson, R. (1999). Project management: Cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. International Journal of Project Management, 17(6), 337–342. 10.1016/S0263-7863(98)00069-6
Ballard, G. , & Howell, G. (2003). Lean project management. Building Research & Information, 31(2), 119–133. 10.1080/09613210301997
Demirkesen, S. , & Ozorhon, B. (2017). Impact of integration management on construction project management performance. International Journal of Project Management, 35(8), 1639–1654. 10.1016/j.ijproman.2017.09.008

Gencer, C. , & Kayacan, A. (2017). Yazılım Proje Yönetimi: Şelale Modeli ve Çevik Yöntemlerin Karşılaştırılması. 335–352. 10.17671/gazibtd.331054
Jiang, J. J. , & Klein, G. (2014). Special Section: IT Project Management. Journal of Management Information Systems, 31(1), 13–16. 10.2753/MIS0742-1222310101
Kumar, A. , Kumar, V. , Modgil, V. , Kumar, A. , & Sharma, A. (2021). Performance analysis of complex manufacturing system using Petri nets modeling method. In Journal of Physics: Conference Series (Vol. 1950, No. 1, p. 012061). IOP Publishing.
Kumar, A. , Kumar, V. , Modgil, V. , & Kumar, A. (2022). Stochastic Petri nets modelling for performance assessment of a manufacturing unit. Materials Today: Proceedings, 56, 215–219.
Lock, D. (2007). Project management (9th ed). Gower.
Morris, P. W. G. (2010). Research and the future of project management. International Journal of Managing Projects in Business, 3(1), 139–146. 10.1108/17538371011014080
Ömürbek, N. , Makas, Y. , & Ömürbek, V. (2015). AHP Ve TOPSIS Yöntemleri İle Kurumsal Proje Yönetim Yazılımı Seçimi. 21, 59–83.
Pasian, B. L. , & Williams, N. L. (Eds.). (2023). De Gruyter Handbook of Responsible Project Management. Walter de Gruyter GmbH & Co KG.
Pinto, J. K. (2002). Project Management 2002. Research-Technology Management, 45(2), 22–37. 10.1080/08956308.2002.11671489
Schieg, M. (2006). Risk management in construction project management. Journal of Business Economics and Management, 7(2), 77–83. 10.3846/16111699.2006.9636126
Schwalbe, K. (2015). Introduction to project management (Fifth edition). Schwalbe Publishing.
Seymour, T. , & Hussein, S. (2014). The History Of Project Management. International Journal of Management & Information Systems (IJMIS), 18(4), 233–240. 10.19030/ijmis.v18i4.8820
Taylor, B. W. (2013). Introduction to management science (11th ed). Pearson.