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(Review)

Engineering's Next Leap: How Fourth Industrial Revolution is Shaping the Future of the Industry

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ABSTRACT

The Fourth Industrial Revolution has triggered a significant transformation in engineering, and this review paper explores its multifaceted contributions. It delves into advanced design and manufacturing techniques that enhance efficiency and creativity. Additive manufacturing and the Industrial Internet of Things play pivotal roles in reducing waste and optimizing productivity. Sustainability takes center stage, with renewable energy and carbon capture technologies offering hope. Electric and autonomous vehicles reshape transportation, while smart cities redefine urban living. Challenges arise in the digitalization of engineering, necessitating adaptability, and ethical considerations. Despite these hurdles, the human spirit of innovation shines through. This review encapsulates the potential of Industry 4.0 in engineering, where boundaries blur, and engineering emerges as a harbinger of a brighter, more sustainable future. Readers are invited to explore this transformative journey, where engineering stands at the forefront of progress.

Keywords: 4IR, Artificial Intelligence, IOT, 5G, Bioengineering

1. Introduction

In the grand tapestry of human history, there have been moments when innovation, ingenuity, and the relentless pursuit of progress have converged to create paradigm-shifting transformations. The First Industrial Revolution ushered in the age of mechanization, while the Second harnessed electricity and brought mass production to life. The Third saw the rise of computers and the digital age [1]. Now, the Fourth Industrial Revolution, marked by the fusion of the physical, digital, and biological worlds, is upon us, promising an era of unprecedented advancement and innovation as shown in Figure 1. At the heart of this revolution is engineering, the vanguard of progress, which finds itself at the epicenter of the dynamic changes sweeping across all aspects of society [2].

This Fourth Industrial Revolution, often referred to as Industry 4.0, is characterized by the convergence of various innovative technologies, including artificial intelligence, the Internet of Things (IoT), blockchain, big data, and advanced robotics as shown in Figure 2. It is a revolution that transcends industry boundaries, reshaping not only how we manufacture products but how we live, communicate, and interact with our surroundings. Within this transformative landscape, engineering is not merely a discipline; it is a driving force shaping the world's future [3]. The contributions of the Fourth Industrial Revolution in engineering are multifaceted and profound. From redefining the way, we design and produce products to revolutionizing infrastructure development and enhancing sustainability, the impact is far-reaching. This exploration will journey through the significant ways in which Industry 4.0 is leaving its indelible mark on the field of engineering [4].

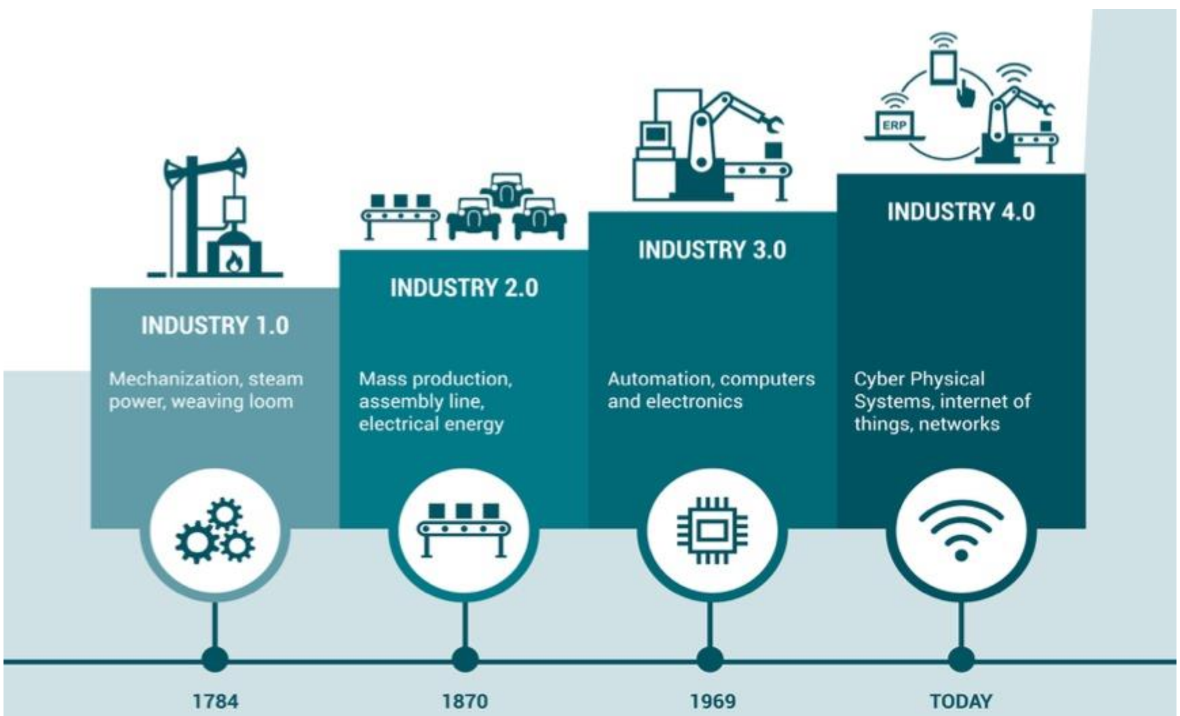

Figure 1. Phases of advancements in fourth industrial Revolution over past years

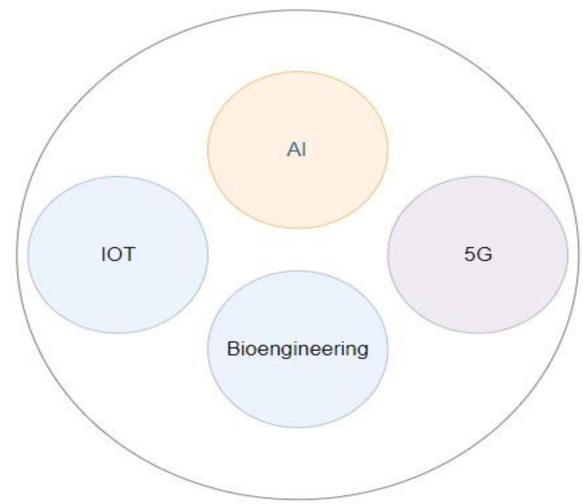

Figure 2. Major technologies of fourth industrial Revolution

- The Transformative Power of Design and Manufacturing

One of the most striking contributions of Industry 4.0 in engineering is the transformative power it bestows upon the design and manufacturing processes. Traditional engineering practices, while effective, often involve lengthy design phases, costly prototypes, and the occasional need for retooling due to unforeseen issues [5]. The advent of advanced simulation and modeling, coupled with the integration of artificial intelligence, has revolutionized the engineering design process. Engineers can now create and test prototypes virtually, simulating real-world conditions and minimizing costly errors. This leap in efficiency significantly reduces both the time and cost associated with product development, giving rise to faster innovation cycles and a surge in creative experimentation [6].

Moreover, additive manufacturing, often known as 3D printing, has emerged as a disruptive force in the production industry. It enables the creation of intricate, customized, and often lighter structures with reduced material waste. 3D printing, with its ability to manufacture complex components, has found applications in aerospace, automotive, healthcare, and many other fields [7]. The impact of such advanced manufacturing techniques extends beyond efficiency in that it fosters a culture of sustainability by minimizing waste, energy usage, and transportation costs.

The Industrial Internet of Things (IIoT), an integral component of Industry 4.0, connects machinery, sensors, and devices in the manufacturing process, creating a seamless flow of data and communication, now engineers can remotely monitor, control, and optimize manufacturing processes. Real-time data analytics empower them to identify and address issues as they arise, enhancing productivity and minimizing downtime. Moreover, predictive maintenance, powered by AI, allows machines to self-diagnose potential faults and schedule maintenance before breakdowns occur. The fusion of design, simulation, and smart manufacturing technologies epitomizes the agility and efficiency that Industry 4.0 has injected into the engineering landscape. These transformative capabilities are not limited to product development but extend to infrastructure design and urban planning, revolutionizing the way we build our cities and interconnected systems [8].

- Engineering Our Sustainable Future

As the world grapples with environmental challenges, engineering has emerged as a beacon of hope in addressing sustainability concerns. The Fourth Industrial Revolution provides engineers with an arsenal of tools to construct innovative solutions to complex environmental issues. The energy sector, for instance, is experiencing a green revolution. Renewable energy technologies, including solar, wind, and hydropower, are gaining momentum, supported by advanced materials, smart grid systems, and efficient energy storage solutions [9]. The engineering of sustainable energy infrastructure goes hand in hand with the development of carbon capture and utilization technologies, which mitigate emissions from industrial processes and convert them into valuable resources. Additionally, IoT-enabled smart grids optimize energy distribution, reducing waste and enhancing grid resilience.

In the transportation sector, engineering innovations are driving the shift towards electric and autonomous vehicles. Advanced batteries and energy management systems are extending the range and efficiency of electric cars, making them more accessible and environmentally friendly. Autonomous vehicles, supported by AI and IoT, promise safer and more efficient transportation systems while reducing traffic congestion and emissions. Sustainability extends to our urban environments as well. Smart city concepts, made possible through Industry 4.0 technologies, facilitate more efficient use of resources, enhanced public services, and improved quality of life for urban dwellers. IoT-driven infrastructure monitoring helps identify and address maintenance needs, while AI-enabled traffic management systems optimize transportation and reduce pollution [10-11].

The field of civil engineering is experiencing a renaissance with the advent of smart infrastructure. Smart buildings and bridges are equipped with sensors that continuously monitor structural integrity, enabling real-time assessment and timely maintenance. The integration of IoT into city planning also extends to waste management, resulting in more efficient waste collection and recycling processes [12].

In the intricate tapestry of this research paper, we embark on an illuminating journey through the profound impacts of the Fourth Industrial Revolution upon the dynamic realm of the engineering industry. Here, we unfurl a rich canvas, adorned with the most significant contributions that this revolution has bestowed upon engineering, resonating like vibrant strokes of innovation on a canvas of progress. But in this article, we are not confined to mere observation; we venture into the future, where we present guidance for researchers to explore the uncharted territories of knowledge. We uncover the strengths that researchers propel forward, daring them to ascend to greater heights.

Hence, this study embarks on a fascinating quest with two pivotal questions:

1. How does the ever-evolving landscape of the Fourth Industrial Revolution in engineering, within the context of sustainable development, unfurl its annual publication trends, spanning the years 2018 to 2023?
2. In this unfolding narrative of innovation, which journals emerge as the torchbearers, illuminating the path toward the symbiosis of the Fourth Industrial Revolution and sustainable engineering?

3. The Fourth Industrial Revolution: What You Need to Know to Thrive in the New Age

The Fourth Industrial Revolution (4IR) is transforming every aspect of our lives, including the field of civil, mechanical, electrical, and communications engineering. 4IR technologies such as artificial intelligence (AI) is the ability of machines to learn and perform tasks without being explicitly programmed. AI is already being used in a wide range of applications, including self-driving cars, medical diagnosis, and customer service [13]. The Internet of Things (IoT) is a network of physical objects that are embedded with sensors and software, and that can collect and exchange data. The IoT is enabling new applications such as smart homes, smart cities, and industrial automation [14]. 5G is the next generation of mobile networks. 5G is significantly faster and has lower latency than previous generations of mobile networks, which will enable new applications such as augmented reality, virtual reality, and self-driving cars [15].
Bioengineering is the application of engineering principles to biological systems to design, build, and develop innovative infrastructure, medical devices, and renewable energy systems that improve human health and well-being [16]. These Technologies are enabling new and innovative solutions to some of the world's most pressing challenges. Overall, 4IR is having a major impact on civil, mechanical, electrical, and communications engineering, and is creating new opportunities for engineers to solve complex problems and make a positive impact on society. In the following subheadings, we will delve into some of the most exciting and transformative applications of the Fourth Industrial Revolution (4IR) in civil, mechanical, electrical, and communications engineering.

4. The 4IR's Legacy on Civil Engineering: Innovation, Infrastructure, and Impact

The Fourth Industrial Revolution revolutionized civil engineering by introducing advanced technologies such as AI, IoT, and big data analytics. These innovations empower engineers to create smarter and more resilient infrastructure, optimize construction processes, and enhance sustainability efforts. In the era of the Fourth Industrial Revolution, civil engineering is poised to deliver efficient, data-driven, and environmentally conscious solutions for our evolving world as shown in Figure 3.

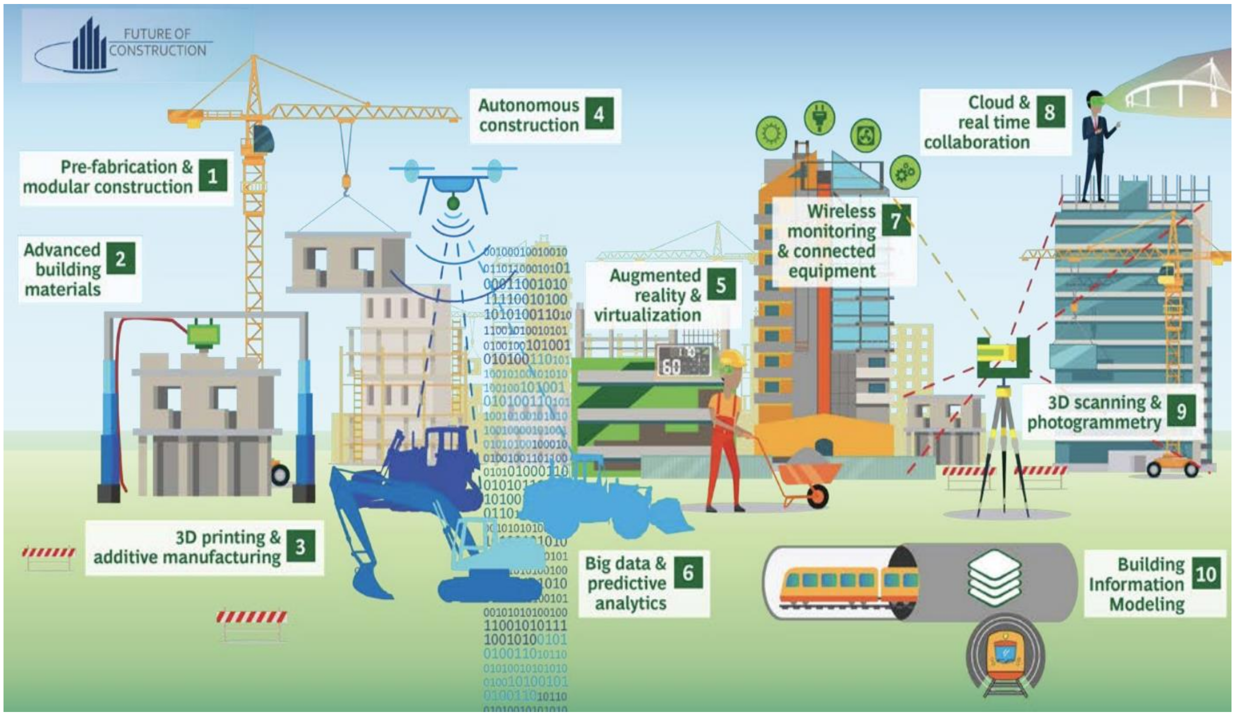

Figure 3. Pioneering Progress: AI's indispensable role in civil engineering—transforming data into smarter, safer, and eco-friendly infrastructure solutions.

AI has become a critical tool in civil engineering, aiding in the design, analysis, and optimization of infrastructure projects. Its ability to process vast amounts of data and simulate complex scenarios helps civil engineers make informed decisions, leading to safer, more cost-effective, and environmentally sustainable construction and infrastructure development.

In the construction industry, preventing accidents and ensuring the safety of workers is paramount. In a recent study,[17] researchers developed a deep learning model to detect the main components of the Personal Fall Arrest System (PFAS). This model, which was trained on a dataset of real-life images, achieved impressive results, scoring over 90% accuracy, precision, and recall. This suggests that the model could be used to reduce accidents in construction projects by helping workers to ensure that their PFAS is properly worn and functioning correctly. Future studies could focus on applying AI to detect other hazards, such as struck-by hazards, which are one of the leading causes of fatalities in construction.

This study [18] aims to improve the efficiency of construction projects by optimizing their duration and expenses. The researchers propose a genetic algorithm-based technique applied to a 5D BIM interface. The algorithm outperforms other methods, resulting in reduced project time and cost. Combining BIM with artificial intelligence methods can yield even better results. The study provides standardized procedures for integrating AI methods and genetic algorithms with the 5D BIM interface. The GA BIM model enhances accuracy and speed, and it can be applied to various multi-objective optimization problems. The research contributes to the knowledge in 5D BIM and AI methodology and suggests future modifications to enhance project management. In conclusion, creative problem-solving is crucial, and the proposed model enables effective handling of

compressions and delays, leading to considerable time and cost savings. Authors have developed a new method to design prefabricated buildings in a way that is both efficient and energy efficient [19]. The method uses genetic algorithms and correlation analysis to optimize the floor plan and component selection of the building. The method was tested on a real-world building in Tianjin, China, and the results showed that it was effective. The scientists also found that the shape of the building and the ratio of windows to walls are strongly correlated with its energy performance. This information can help architects to design more energy-efficient buildings.
3D printing is now a key player in various industries, and its reach keeps growing. Recently, architectural design has embraced parametric design, and many industries are adopting topology optimization as a standard part of their design process. Researchers developed a new traffic signal control system [20] that uses AI to learn from experience and optimize signal patterns to minimize congestion. Their system outperformed traditional fixed-time signals and constraint-free AI signals in simulations, but it needs to be tested in real-world intersections.

In railway engineering, keeping the passing trains and the track bed's condition in top shape is crucial for a safe subway system. By closely watching how the track bed responds to vibrations and spotting any unusual signals, we can tackle these principal issues head-on. This study [21] shows that unsupervised learning can identify anomalous vibration signals in subway tunnel track bed responses using ultra-weak FBG sensing arrays. Adequate normal vibration samples are crucial for training the network and auxiliary detection. However, obtaining enough abnormal samples proved challenging, limiting the pattern diversity for various levels of anomalies. Further testing and improvement are needed to assess the method's recognition effect on unknown samples with significant type differences. Despite this limitation, the proposed method demonstrates robustness in real-world engineering scenarios due to random selection of source and location for simulated abnormal samples. The study acknowledges other limitations, including the need for more unknown types and degrees of abnormal events to improve the unsupervised learning network architecture. Additionally, the quantification of error sequences and the influence of normal sample size on identification effectiveness require further investigation. Future work should focus on obtaining more typical anomaly samples and validating the proposed method in similar areas.

In earthquake engineering, understanding how the ground amplifies seismic forces is a top priority when assessing earthquake safety. The Authors utilized a 1-D CNN method to predict ground motion amplification in the Lower Hutt Valley [22]. Two CNN models were established and applied, using a small sample dataset. The prediction results were inspiring, leading to the following conclusions. The trained CNN models were less influenced by different training parameters compared to BNPP models, resulting in a more stable trained model. The CNN-FSPA model effectively predicted station amplification factors with 91.5% accuracy, surpassing the corresponding BPNN-FSPA model by 15.8%. Both CNN-FSPA and CNN-PSPA models successfully predicted local ground motion amplification factors. Comparisons between the models indicated that by increasing the number of earthquakes and training samples, a ground surface amplification prediction model could be established based on strong earthquake observations.

The integration of IoT (Internet of Things) in civil engineering has significantly enhanced monitoring and management of infrastructure. By deploying sensors and connected devices, civil engineers can gather real-time data on structural health, traffic conditions, and environmental factors, enabling proactive maintenance and more efficient resource allocation for improved safety and sustainability in the field. The authors in study [23] proposed an automatic response measurement method for detecting cracks and deflections in structures. The existing methods lack simultaneous detection of these parameters. The proposed method consists of three components: a continuous image acquisition and signal transmission system using a self-walking bracket and Internet of Things (IoT), an image splicing method based on feature matching, and a crack and deflection measurement method. The self-walking bracket enables the industrial camera to capture continuous images of the beam at a fixed distance. The spliced image is obtained using the PCA-SIFT method with a screening mechanism. The cracks' information is acquired using a dual network model, and the structures' natural features are tracked using a simplified AKAZE feature detection algorithm and modified RANSAC. Curve fitting is applied to obtain the deflection curve of the beam under different loads. Experimental results demonstrate that the method accurately reflects the crack and deflection information, with average deviations of 11.76% for width, 8.18% for length, and 4.50% for deformation. These findings validate the practicality of the method and highlight its potential for real-world structural applications.

In [24] proposed a deep belief network-based method to predict the durability of concrete structures under complex environmental conditions. The method considers both concrete material properties and external environmental factors, and it starts by describing the transmission of chloride ions in the concrete structure. It then uses a deep belief network trained on concrete structural anti-flexural strength judgment data to predict the durability of the concrete structure. Simulations show that the proposed method has a high prediction accuracy of 98% for the durability of concrete column structures, and it is much faster than traditional methods. This could have a significant impact on the improvement of concrete durability test methods and evaluation standards in China.

5G networks have the potential to revolutionize the construction industry by enabling automation and digitization. This paper presented a framework for using 5G to address the challenges of this sector, including security, privacy, and device capabilities [25]. Future work will focus on developing more applications and algorithms to exploit the full potential of 5G in construction. The authors in study [26] proposed an IoT and 5G-enabled construction detection model to address the challenges of traditional methods, which are often slow and inaccurate. The model uses 5G to transmit data from the object dataset to IoT devices faster, enabling enhanced on-site detection and off-site data streaming. The proposed model's benefits include cost reduction, construction duration reduction, quality improvement, sustainability improvement, and enhanced safety. It has the potential to revolutionize the construction industry by making it more efficient, productive, and safer.

Bioengineering has a vital role in civil engineering by providing sustainable solutions for environmental challenges. Using biological systems, such as plants and microorganisms, bioengineering techniques help stabilize slopes, control erosion, and improve soil quality, contributing to the long-term durability and ecological harmony of civil engineering projects [27]. Imagine a living wall that not only holds back the soil, but also provides habitat for wildlife, cleans the air, and stores carbon. That is the power of living soil retaining walls (SWBEs). SWBEs are a type of green infrastructure that is becoming increasingly popular, but more research is needed to assess their full impact. This study [28] is a step in the right direction, providing insights into the potential negative impacts of SWBE construction and the need for more holistic assessments. In the future, researchers will focus on developing models to better understand the full life cycle of SWBEs and their positive impacts. They will also develop databases of monitoring data to inform these models and help us to determine whether SWBEs can truly achieve ecologically positive effects. SWBEs are a promising technology for creating more sustainable and resilient communities. With more research, we can unlock their full potential. While the Krishna Bhir and Banepa Bardibas Highway projects faced some challenges [29], bioengineering has the potential to revolutionize hill road construction in Nepal. With proper training, planning, and maintenance, bioengineering techniques can be used to create roads that are both strong and sustainable. Nature's helping hand can help us to build better roads for a better future.

5. The 4IR's Legacy on Mechanical Engineering: Mechanization, Modernization, and Momentum

The Fourth Industrial Revolution was instrumental in transforming mechanical engineering by integrating innovative technologies like IoT, artificial intelligence, and automation into manufacturing processes. These innovations enhance production efficiency, enable predictive maintenance, and optimize supply chains. Mechanical engineers are harnessing the power of Industry 4.0 to create smarter, more agile, and sustainable mechanical systems that drive economic growth and innovation as shown in Figure 4.

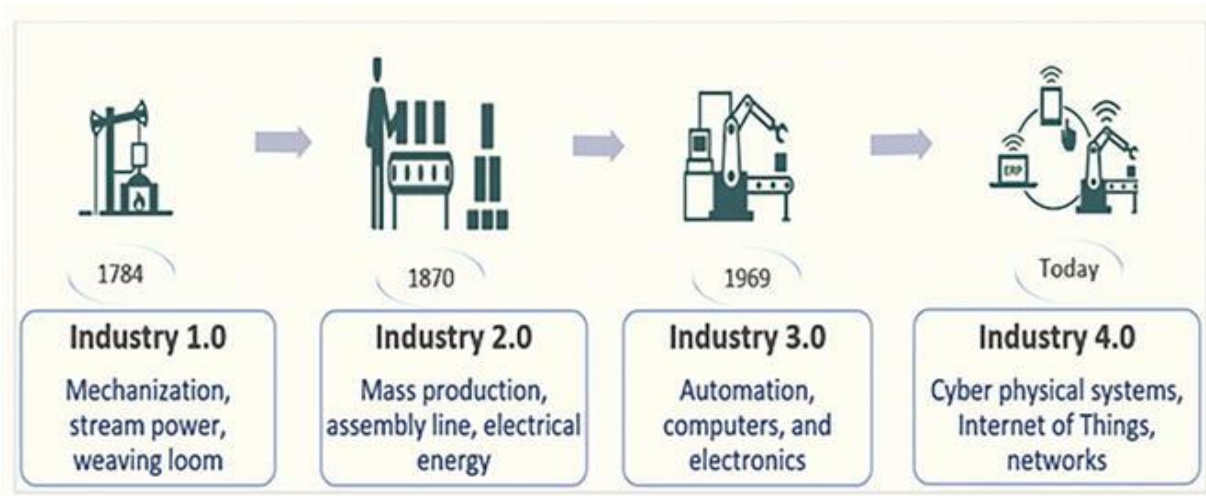

Figure 4. Forging the Future: The Fourth Industrial Revolution reshaping mechanical engineering—where innovation meets efficiency, precision, and sustainability.

Artificial Intelligence has revolutionized mechanical engineering by enhancing the design and optimization processes, allowing for the development of more efficient and sustainable products. AI-driven predictive maintenance also plays a vital role in ensuring the longevity and reliability of complex machinery, reducing downtime and maintenance costs. Pandemics, exemplified by COVID-19, pose escalating health risks to manufacturing systems, causing profound disruptions. Intelligent manufacturing (IM) systems, featuring sensor-monitored automation and smart algorithms, offer a path to safer working environments. By utilizing IM technology, this study [30] pioneers a framework for pandemic-driven production recovery, deploying an assessment model to gauge IM's impact on industrial networks. Furthermore, it optimally allocates IM resources, aligning with market demands and pandemic severity, reducing industrial chain disruption. Data-centric AI prioritizes data understanding and quality, benefiting mechanical engineering by predicting component failures through real-time sensor data [31]. This enables proactive maintenance, reducing downtime and enhancing process optimization for production parameters. Overall, AI elevates mechanical system efficiency and standards.

The integration of IoT in mechanical engineering enhances equipment monitoring and predictive maintenance, ensuring optimal performance, reducing downtime, and preventing costly machinery failures. This research paper [32] presented an innovative approach to 'Engineering Education' in Robotics for Mechanical Engineering Technology (MET). Remote robotics classes are currently implemented globally due to the pandemic, hindering hands-on practices. To address this, an efficient method utilizing Internet of Things (IoT) based projects is proposed. This approach involves wireless sensor networks, remote collaboration, and modular design, allowing students to engage in hands-on projects, practice control theories, and gain valuable robotics experience. The Internet of Things (IoT) has emerged as a crucial element in distributed sensing applications, allowing smart entities to communicate within a pervasive network. However, the reliance on batteries for power poses limitations due to their finite lifetime and impractical replacements. To address this, energy-autonomous technologies like Energy Harvesters (EHs) leveraging MEMS technology are introduced. This review [33] focused on vibration EHs, which convert environmental mechanical energy into electricity. The discussion delves into the challenges of scaling down EHs and extending their operability across a broad range of vibrations.

5G technology plays a crucial role in mechanical engineering by providing high-speed, low-latency connectivity, enabling real-time data transfer for remote equipment monitoring, control, and efficient decision-making, improving the performance and reliability of mechanical systems. The authors [34] introduced an innovative, inkjet-printed, and versatile antenna for 5G networks operating in millimeter-wave frequency bands, featuring reconfigurable radiating patches via switchable slots. Furthermore, it proposes a flexible MIMO antenna assembly, suitable for high-performance 5G front ends, as well as wearable electronic devices, enhancing the adaptability and efficiency of next-generation wireless applications. The constructive collaboration between 5G and AI is transforming industrial production, addressing the escalating demand for high-speed data transmission and rapid analysis of the growing production data. Traditional methods fall short in achieving peak performance and analysis speed, making the integration of 5G and AI paramount. A case study [35] conducted at the Advanced Manufacturing Technology Center (AMTC) illustrates the benefits and potential of these technologies, emphasizing their significance in enhancing industrial processes.

Bioengineering in mechanical engineering plays a pivotal role by offering nature-inspired solutions for materials, structures, and mechanisms, contributing to the development of innovative and sustainable mechanical systems. Biomechanics finds a dynamic role in sports, analyzing individual movements for enhanced performance, while guiding the design of optimized sports gear. Additionally, it aids in injury prevention and treatment, ensuring athletes reach their full potential while staying safe, serving as a multifaceted asset in the athletic world [36]. In a recent study [37] comparing bionic hands to customized body-powered technology in a demanding work setting, the findings revealed that the customized body-powered arm surpasses the iLimb system in terms of reliability, comfort, efficiency, power, and precision, with significantly reduced maintenance requirements. This research underscores the practical advantages of tailored solutions in prosthetic technology, offering a more dependable and user-friendly alternative in demanding applications.

6. The 4IR's Legacy on Electrical and Communications Engineering: Powering the World and Connecting the Globe

The Fourth Industrial Revolution has profound implications for electrical and communication engineering, as its ushers in advanced technologies such as 5G, IoT, and AI, which underpin the development of smart cities, connected devices, and more efficient communication systems. This revolution empowers engineers to design robust, high-speed networks, improve data transmission, and enhance the reliability and security of electrical systems. The fusion of digitalization and connectivity in the Fourth Industrial Revolution is pivotal for creating more responsive and interconnected electrical and communication solutions, shaping the way we communicate and consume energy as shown in Figure 5.

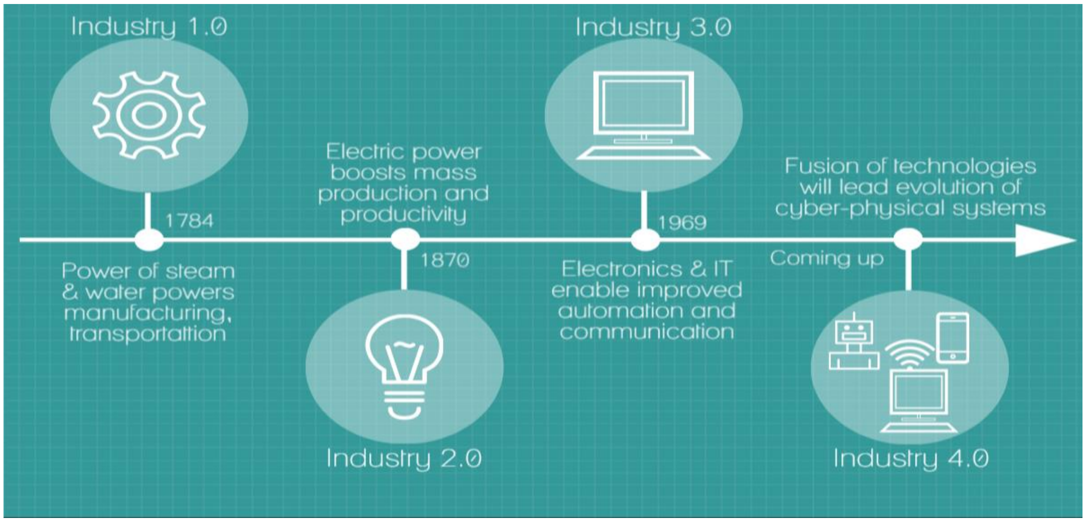

Figure 5. Powering Progress: The Fourth Industrial Revolution redefining electrical and communication engineering—where innovation meets seamless connectivity, energy efficiency, and advanced technologies.

AI revolutionizes electrical and communication engineering by optimizing network performance, enhancing signal processing, and enabling efficient resource allocation, leading to more reliable and responsive communication systems. This paper [38] explored the impact of digital technology indicators, such as the ICT index, on various sectors, including banking, manufacturing, schools, and hospitals in the era of Industry 4.0. Combining qualitative and quantitative analyses, the research demonstrates that the integration of ICT, AI, and IoT technologies significantly enhances electrical engineering and the electric industry, driving improved productivity, data management, and communication channels while underscoring the importance of robust cybersecurity measures in this rapidly evolving landscape. Addressing contemporary challenges in communication engineering, this paper [39] introduced an innovative system that merges artificial intelligence with traditional methods, emphasizing information security in the era of 5G technology. By infusing AI thinking and 5G advancements, the system enhances communication engineering security, presenting promising results for fortified information safety and the evolution of 5G technology. This paper [40] distinguished between mind and cognition, positing that cognition is an aspect of mind. This working hypothesis, called the Separability Hypothesis, can help to avoid philosophical objections raised about the "Strong AI" hypothesis, which holds that machines can achieve human-level intelligence. It is unlikely that a single architectural level will explain all cognitive phenomena, as there are multiple interacting levels, unlike in computer models. Artificial intelligence techniques are permanent, consistent, and well-documented, making them valuable for developing modern technologies in high-voltage power supplies and other fields of electrical engineering. The article [41] delved into the integration of artificial intelligence into electrical automation control systems (EACS), highlighting AI's transformative impact on the field. By harnessing AI's capabilities, electronics and instrumentation applications stand to vastly improve their performance, ushering in a new era of intelligent operation, security, and innovation. While AI has already made substantial strides in this domain, there remains room for further development and refinement, explored in-depth within this article.

IoT is pivotal in electrical and communication engineering as it enables seamless connectivity, real-time data exchange, and smart automation, optimizing network performance and facilitating efficient resource management in an increasingly interconnected world. The COVID-19 pandemic has ushered in a profound shift in daily life, emphasizing the significance of smart cities as solutions that harness technology to enhance services across critical sectors like healthcare, education, energy, and transportation. This article introduced [42] two forward-looking IoT applications within smart cities: the first involves an intelligent health monitoring system, aimed at curbing the transmission of infections and reducing healthcare staff workload, while the second monitors and optimizes electrical energy consumption and power line security through real-time data collection and transmission via sensors.

IoT plays a pivotal role in enhancing the monitoring of coma patients, potentially saving up to 60% of lives through early detection. The specially designed device employs GSM and IoT technology to continuously track critical health parameters, including temperature, heart rate, eye movements, and oxygen saturation [43]. Utilizing an ARDUINO-UNO board and cloud computing, the system records and transmits vital patient data to authorized individuals' smartphones and laptops via a cloud server, enabling real-time analysis and informed decision-making.

5G technology is of paramount importance in electrical and communication engineering, enabling faster data transfer, reduced latency, and improved connectivity, which are essential for powering advanced communication systems, the Internet of Things (IoT), and smart grid applications. This study [44] introduced a cutting-edge 4-element MIMO antenna system with a single-layer meta surface array designed for 5G millimeter-wave communication. Leveraging innovative CSR-shaped cell meta surface, the antenna enhances gain and isolation between elements, operating at the 24.55-26.5 GHz frequency band. With significant improvements in gain and isolation, along with favorable MIMO metrics like ECC, DG, CCL, and MEG, the antenna's performance establishes its suitability for future 5G communication systems.

In the race to realize 5G's potential, millimeter-wave (mmWave) antennas for smartphones emerge as vital components, yet a standardized design remains elusive. This communication [45] introduced the "clover antenna," a novel mmWave 5G antenna for cellular handsets offering high gain and broad bandwidth. Through simulation and real-world testing in the 24-28 GHz band, the antenna exhibits a measured peak gain of 7.8-9 dBi and beam-steering capability. Practical considerations for array integration are explored, highlighting the antenna's potential for comprehensive horizontal coverage and its effects on spatial power density.

Bioengineering contributes to electrical and communication engineering by inspiring innovations in bioelectronic devices, biosensors, and bio-inspired signal processing techniques, bridging the gap between biological systems and electronic technologies to develop advanced medical devices and communication solutions. This research [46] explored the enhancement of small amplitude biomedical signals, extending their range from millihertz to kilohertz by eliminating direct current components. It introduces a Bio Signal OTA with impressive characteristics, designed in a 90-nanometer CMOS technology, highlighting a high gain, low noise, and minimal power consumption. The study also delves into several types of OTAs used in bio imaging, highlighting the innovative use of a Wilson current mirror to achieve outstanding Common Mode Rejection Ratio (CMRR), Power Supply Rejection Ratio (PSRR), and Gain-Bandwidth Product (GBW) in this bio-OTA design.

In a world where biology communicates through ions and molecules, and technology speaks in electrons, there is a growing need to bridge this gap. To seamlessly integrate biological and artificial systems, bioinspired ion-transport-based sensory systems are emerging as the successors to traditional electronics. The article [47] explored the principles of accurate ion transport and reviews recent advancements in ionic sensors, processors, and interfaces, shedding light on the current challenges and prospects in the realm of ion-transport-based sensory systems, where biology and technology converge.

In an era of information overload, automated text summarization methods are indispensable for extracting key content from large documents. Manual summarization is arduous and time-consuming, making automated solutions vital. This paper [48] introduced a novel hybrid approach (CSOGA) that combines Chicken Swarm Optimization (CSO) and Genetic Algorithm (GA) for text summarization. The CSOGA method outperforms other algorithms in terms of text summarization quality, achieving significant accuracy improvements in ROUGE-1, ROUGE-2, and ROUGE-L metrics, offering a promising solution for efficient content extraction in a data-intensive world.

7. Discussion

The Fourth Industrial Revolution (4IR) has ushered in a transformative era in engineering, redefining the way we conceive, design, and implement solutions across various engineering disciplines. As a fusion of digital, physical, and biological systems, 4IR technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), and advanced automation, have left an indelible mark on the engineering landscape. This brief introduction explores the profound impact of 4IR on engineering, highlighting its role in enhancing efficiency, sustainability, and innovation while presenting new challenges and opportunities for engineers worldwide. Figure 6. Researchers' interest in using the Fourth Industrial Revolution and its impact on engineering shows the extent, as scientific papers published in indexed journals have increased over the past years.

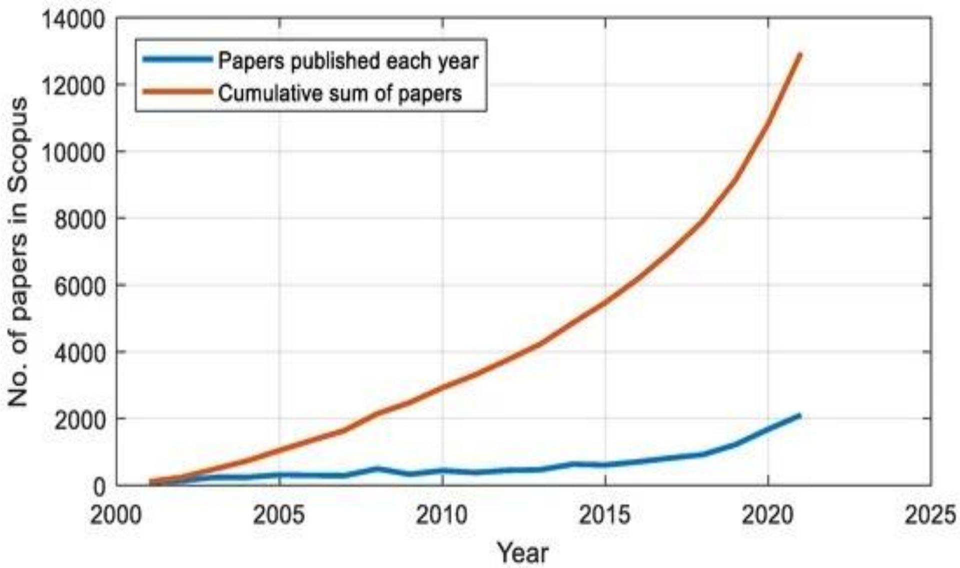

Figure 6. Published articles (in Scopus) using 4IR in engineering-related fields (2000–2023).

The Fourth Industrial Revolution has brought a wave of innovation to civil engineering. Technologies like Artificial Intelligence (AI), Internet of Things (IoT), and big data analytics have empowered civil engineers to design smarter and more sustainable infrastructure. AI is now a crucial tool in civil engineering, helping with everything from safety to efficiency. For instance, AI can detect construction hazards and optimize project timelines, resulting in safer and more cost-effective construction. In construction, AI is helping to prevent accidents by detecting the proper use of safety equipment. Researchers have achieved impressive results, scoring over 90% accuracy in detecting Personal Fall Arrest System (PFAS) components. This technology holds the potential to reduce accidents and improve construction site safety. Additionally, AI is optimizing project management, leading to reduced project time and costs. Researchers have used genetic algorithms with Building Information Modeling (BIM) to streamline project planning, which could result in considerable time and cost savings. In the realm of earthquake engineering, AI is being used to predict ground motion amplification. The models achieved a remarkable 91.5% accuracy in predicting station amplification factors, highlighting the potential to enhance earthquake safety. The integration of IoT in civil engineering has transformed infrastructure monitoring. With IoT sensors, civil engineers can gather real-time data on structural health, traffic conditions, and environmental factors. This data is instrumental for proactive maintenance and resource allocation, improving safety and sustainability. In construction, 5G technology is poised to revolutionize the industry by enabling automation and digitization. Researchers are working on IoT and 5G-enabled construction detection models to expedite data transmission, reduce costs, and improve overall efficiency in construction projects. Bioengineering is making an impact by offering sustainable solutions for environmental challenges. Techniques like living soil retaining walls (SWBEs) can stabilize slopes, control erosion, and improve soil quality while providing habitat for wildlife and contributing to a cleaner environment.

Engineering will be greatly impacted by the fourth Industrial Revolution, which is defined by the merging of technologies that make it harder to distinguish between the digital, biological, and physical domains. Because they create and use the cutting-edge technologies that enable this revolution's revolutionary developments, engineers are leading the charge. Engineers facilitate the development of smart factories and the implementation of Industry 4.0 concepts by use of sophisticated production processes such as automation and additive manufacturing. Furthermore, the creation of artificial intelligence (AI) algorithms, cyber-physical systems, and Internet of Things (IoT) technologies—all crucial to the fourth Industrial Revolution—requires technical knowledge. Engineers also play a critical role in addressing sustainability challenges by designing eco-friendly technologies and sustainable infrastructure. Overall, engineering drives innovation, shapes technological progress, and propels society forward in the fourth Industrial Revolution. By creating environmentally friendly technology and sustainable infrastructure, engineers also contribute significantly to solving sustainability issues. In general, engineering is what fuels innovation in the fourth Industrial Revolution, determines technical advancement, and advances civilization.

Challenges in civil Engineering during Fourth Industrial Revolution:

During the Fourth Industrial Revolution, civil engineering faced a range of challenges. One of the foremost concerns is cybersecurity. The increased reliance on digital technologies, the Internet of Things (IoT), and Artificial Intelligence (AI) exposes civil engineering systems to cybersecurity threats. Protecting critical infrastructure from cyber-attacks and data breaches is a significant challenge, requiring robust security measures and constant vigilance.

Handling the immense volume of data generated by sensors and IoT devices is another challenge. Efficient data management is crucial, encompassing data storage, processing, and analysis methods. Civil engineers must develop and implement systems capable of handling this data deluge effectively while maintaining data integrity and accessibility.

The integration of various technologies is a complex challenge in the Fourth Industrial Revolution. Bringing together diverse technologies such as AI, IoT, and 5G into existing infrastructure while ensuring seamless compatibility is not a straightforward task. Achieving interoperability and avoiding technical conflicts demand careful planning and execution.

The skills gap poses a significant challenge. There is a growing need for engineers and professionals with expertise in the innovative technologies transforming civil engineering. Bridging the skills gap and ensuring the workforce is adequately trained to leverage these technologies is critical for successful implementation.

Navigating regulatory hurdles is another challenge. Regulations often struggle to keep pace with the rapid advancements in technology. Civil engineers and policymakers must work together to adapt and develop regulatory frameworks that both promote innovation and ensure public safety.

Data privacy concerns are on the rise. The extensive collection and use of data for various purposes raises questions about data privacy and ethical use. Balancing the benefits of data-driven insights with respect for privacy is an ongoing challenge in the Fourth Industrial Revolution.

Infrastructure resilience is a vital concern, particularly in the face of natural disasters and extreme weather events. Ensuring that smart infrastructure can withstand and recover from such events remains a challenge that civil engineers must address through innovative design and planning.

Sustainability remains a central focus, but it comes with its own challenges. While technology can enhance sustainability efforts, civil engineers must balance sustainability goals with the demands of rapid urbanization and infrastructure growth. Achieving a harmonious equilibrium between growth and sustainability is a constant challenge.

The cost of implementing innovative technologies is a significant concern. The adoption of Fourth Industrial Revolution technologies can be costly. Finding sustainable funding models for these innovations in the face of budget constraints and financial uncertainties is a challenge that civil engineers and decision-makers must navigate.

Lastly, gaining public acceptance of smart infrastructure is a challenge. This pertains to technology and concerns related to data collection and privacy. Building public trust and acceptance is essential for the successful deployment of these innovative solutions in civil engineering projects.

In mechanical engineering, Industry 4.0 is transforming manufacturing processes. AI-driven predictive maintenance reduces downtime and maintenance costs, while IoT enhances equipment monitoring and performance. Electrical and communication engineering are also experiencing significant changes. AI is optimizing network performance, enhancing signal processing, and improving information security. IoT ensures less connectivity and real-time data exchange, and 5G technology facilitates data transfer and reduces latency. Bioengineering is inspiring innovations in bioelectronic devices and signal processing, bridging the gap between biology and technology. These innovations hold the potential to develop advanced medical devices and communication solutions.

Challenges in Mechanical Engineering during the Fourth Industrial Revolution:

The Fourth Industrial Revolution introduced several notable challenges to the field of mechanical engineering. Firstly, the efficient integration of advanced technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), and automation, into mechanical systems is a complex task. Engineers must ensure compatibility and reliability, particularly in systems that have traditionally operated independently. Secondly, there is a significant skills gap in the workforce. Nurturing a workforce with the expertise needed to harness emerging technologies and fostering a culture of continuous learning is imperative to meet the demands of Industry 4.0. Additionally, sustainability is a critical concern. Striking a balance between innovation and sustainability goals, including resource efficiency, and reduced environmental impact, is an ongoing challenge for mechanical engineers. The vast amount of data generated by IoT sensors and smart machinery presents another challenge. Mechanical engineers must develop effective data management strategies while ensuring data security and integrity. Finally, implementing predictive maintenance strategies to reduce downtime and maintenance costs, while also ensuring the reliability of complex machinery, is a priority that requires advanced analytics and robust strategies.

Challenges in Electrical Engineering during the Fourth Industrial Revolution:

In the realm of electrical engineering, challenges abound during the Fourth Industrial Revolution. Cybersecurity is a foremost concern. Protecting electrical systems, IoT devices, and data from cyber threats in an increasingly interconnected world is a critical challenge that demands constant vigilance. Rapid technological advancements also pose a challenge. Electrical engineers must keep pace with the ever-evolving landscape of technology and ensure that electrical infrastructure remains up-to-date and capable of supporting new innovations. Implementing smart grid systems is another complex task. Developing and deploying smart grids that enhance energy distribution and management while maintaining grid stability and reliability is a multifaceted challenge. Balancing the growing energy demands of an interconnected world with the need for energy efficiency is an ongoing concern, particularly as the number of connected devices and systems increases. Interoperability is also essential. Ensuring compatibility and interoperability between various electrical and electronic systems is vital for seamless operation and efficient utilization of resources.

Challenges in Communication Engineering During the Fourth Industrial Revolution:

Communication engineering faces unique challenges in the era of the Fourth Industrial Revolution. Data security is paramount, as safeguarding data transmitted over networks, especially in IoT applications, from cyber-attacks and breaches is a paramount challenge. The growing demand for high-speed data transfer, low latency, and connectivity in the era of 5G technology presents a challenge. Engineers must ensure that networks can scale to meet these demands efficiently. Efficiently managing and allocating the limited radio frequency spectrum for wireless communication is another challenge, as it is essential to avoid interference and congestion. Privacy concerns also need to be addressed. Balancing the public's concerns about data privacy with the benefits of interconnected devices and smart systems is an ethical and technical challenge for communication engineers. Lastly, the convergence of technologies like IoT, 5G, and AI in communication systems requires careful management to ensure seamless operation and maximum efficiency. Engineers must navigate this convergence effectively to meet the demands of Industry 4.0.

This extensive chart gives a complete overview of the main problems and concerns within each field by outlining the difficulties experienced by different engineering areas throughout the fourth Industrial Revolution.

Table 1: Challenges in Engineering Disciplines during the Fourth Industrial Revolution

Engineering Branch	Challenges	Importance (1-5)
Communication Engineering	• Managing massive data influx from IoT devices • Ensuring robustness of communication networks	5 4
Mechanical Engineering	• Adapting to rapid advancements in additive manufacturing and automation • Developing flexible and adaptive manufacturing systems	5 4
Electrical Engineering	• Designing energy-efficient technologies and smart grids • Developing advanced electrical and electronic systems for IoT devices	4 5
Civil Engineering	• Integrating IoT sensors into infrastructure projects for monitoring and management • Addressing sustainability challenges in infrastructure construction	4 5

8. Conclusion

In conclusion, this review article provides a comprehensive overview of the Fourth Industrial Revolution (4IR) and its impact on engineering disciplines. The 4IR has brought about a new era of technological advancements, including artificial intelligence, robotics, IoT, big data analytics, and advanced manufacturing. The integration of these technologies in engineering has led to transformative changes, enhancing productivity, efficiency, and innovation across various sectors. The growing interest in the 4IR is evident in the significant increase in research papers published on the topic. Collaboration patterns and co-citation networks highlight the interdisciplinary nature of the 4IR, emphasizing the need for cross-disciplinary approaches to address its challenges and opportunities. Specific engineering disciplines, such as civil, electrical, mechanical, and industrial engineering, have been extensively studied in the context of the 4IR, highlighting diverse applications and implications. However, the 4IR presents both challenges and opportunities for engineering, including concerns about job displacement, ethical considerations, and the need for up skilling the engineering workforce. The literature emphasizes the importance of leveraging 4IR technologies to enhance sustainability, resilience, and safety in engineering practices. Emerging topics include AI for predictive maintenance, robotics in automated manufacturing, IoT in smart infrastructure, and data analytics for decision-making. The continuous growth in research papers reflects the ongoing exploration and advancements in the field. Addressing research gaps, such as the social and ethical implications of the 4IR in engineering and effective integration frameworks, will be crucial for future studies. Overall, this review article highlights the considerable influence of the 4IR on engineering disciplines and the potential for engineering to lead and shape the future in this era of technological transformation.

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Conflict of Interest

A declaration of conflict of interest.

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