A narrative review on use of biomaterials in achieving SDG 9: build resilient infrastructure, promote sustainable industrialization and foster innovation

Rajat Gera[1*], *Priyanka* Chadha[2], *Sonali* P Banerjee[3], *Mona* Sharma[4], *Amit Kumar Pandey*[4], *Shivani* Kampani[5], *Saurav* Dixit[6], *Suresh Kumar* Tummala[7], *M. Abdulfadhil* Gatea[8,9]

[1]Director Research, Woxsen University, Hyderabad, Telengana
[2]Amity business school, amity university Noida , India
[3]Amity business school, amity university Noida , India
[4]Manav Rachna University Faridabad, India
[5]K R Manglam University , India
[6] Division of Research & Innovation, Uttaranchal University, India
[7] Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, INDIA
[8] Technical Engineering Department College of Technical Engineering, The Islamic University, Najaf, Iraq
[9] Department of Physics, College of Science, University of Kufa.

Abstract This study aims to address the gaps in the existing literature on the use of biomaterials in achieving SDG 9, identify gaps in current knowledge, and provide insights for future research directions. A narrative review of 62 papers published between 1996-mid 2023 in which use of biomaterials in achieving SDG 9 (build resilient infrastructure, promote sustainable industrialization and foster innovation) shows that biomaterials have great potential to transform the construction and infrastructure industries by providing sustainable, biodegradable, and cost-effective alternatives to traditional materials. The use of biomaterials and new technologies in various industries has the potential to create significant economic, social, and environmental impacts. However, realizing these benefits requires investment in research and development, improving production processes, and creating policies that support the use of sustainable biomaterials. There is a need to consider the sustainability and environmental impact of biomaterials in various applications, including medical devices, orthopedic biomaterials, and biofuels, among others. Their development and implementation may require supportive policy and governance frameworks. Future research directions can focus on several areas such as optimization of biocompatibility and biodegradability of biomaterials, developing scalable and cost-effective manufacturing processes for sustainable biomaterials.

* Corresponding Author: geraim43@gmail.com

Keywords: sustainable biomaterials, literature review, environmentally friendly products, sustainable technologies

1. Introduction:

"Transforming our world: the 2030 Agenda for Sustainable Development" [1] was accepted by the UN General Assembly on November 25, 2015. The 2030 Agenda emphasises the attainment of sustainable development for all by building on the idea of "leaving no one behind" and asks for cooperative partnerships at all levels. Since their implementation on January 1, 2016, the Sustainable Development Goals (SDGs) have served as the primary benchmark for development policies designed to promote sustainability in all its dimensions, including economic, social, and environmental, until 2030. Countries' advancement towards meeting each SDG is tracked through the SDG index and Dashboards [2]. SDG-9 indicators that apply to the industrial sector. Manufacturing may be helpful for creating long-term plans for (re-)industrialization in certain nations, but it is impossible to set a standard global threshold for such plans [3].

Biomaterials are substances made from living things or their byproducts, and they have a wide range of uses in a variety of sectors, including manufacturing, agriculture, and the medical field. Several ways that biomaterials can aid in achieving SDG 9 include:

1.1 Innovation: Biomaterials research and development can result in the development of brand-new, environmentally friendly products and technology. Biomaterials, for instance, can be utilized to create biodegradable polymers, which can lower pollution and plastic waste. Research and development in biomaterials can result in the development of innovative, environmentally friendly products and technology. Biomaterials, for instance, can be utilized to create biodegradable polymers, which can lower pollution and plastic waste. In addition, biomaterials can be employed to develop novel medical devices, such as implantable materials with improved biocompatibility and tissue integration. Over time, this may lead to better patient outcomes and lower healthcare expenditures. High-tech enterprises may be more environmentally friendly than other industries from a technological and innovative standpoint since they produce less pollution [4]. For instance, the recycling sector is the ideal option for generating continuous growth because it creates equity and jobs while also being ecologically benign [5]. According to Chakraborty and Mazzanti [6], boosting research and development spending on green energy technology is crucial for cutting down on energy intensity.

New and better infrastructure, such as structures and bridges, can be created using biomaterials. For instance, tougher and more resilient concrete can be produced using biomaterials, which over time may help to lower maintenance and repair costs. Buildings and bridges can be constructed using biomaterials in new and improved ways. By adding components like bamboo, straw, or hemp fibres to concrete, for instance, biomaterials can be employed to make it stronger and more resilient. Concrete's performance can be improved by these materials, increasing its resilience to dangers like earthquakes and fire. Additionally, self-healing fabrics that can fix rips and damage on their own can be made using biomaterials, which eliminates the need for pricey repairs and upkeep. SDG 9 (industry, innovation, and infrastructure) includes infrastructure; however it is widely acknowledged that infrastructure helps sustainable development in a variety of ways [7],[8].

1.2 Industry: By producing and manufacturing items based on biomaterials, for example, new industries and jobs can be created using biomaterials. Particularly in rural areas, this can support economic growth and development. In the creation and manufacture of products based on biomaterials, for example, biomaterials have the potential to launch new businesses and generate employment. This can encourage economic growth and development, especially in rural places where resources from the area can be used to make biomaterials. For instance, making bioplastics from plant-based materials like corn or sugarcane may open up new commercial options for farmers and small companies. Additionally, the usage of biomaterials can lessen dependency on petrochemicals and fossil fuels, improving the sustainability and long-term resilience of industries.

There have been numerous evaluations of the literature on biomaterials and how they might help achieve SDG 9. Here are a few illustrations of their conclusions:

The authors examined the function of biomaterials in sustainable development in a review article that was published in the Journal of Materials Science. They emphasized how biomaterials might potentially open up new doors for economic expansion and development, particularly in rural areas. They also talked about how using biomaterials may help different businesses have a less negative influence on the environment, including using biodegradable plastics to cut down on pollution and waste from plastics. The potential for biomaterials to enhance healthcare outcomes was also mentioned, including the creation of implantable materials that would better integrate with the patient's tissues. Ashby defines sustainable material as “a material [which] must be drawn from a source that is renewable, either because it grows as fast as we use it or because it reverts to its original state on natural decay and does so in an acceptable time span” [9]. The resource and the material must be a part of the nitrogen, carbon, or hydrological cycles of nature, allowing the nitrogen, carbon, and water to be recycled.

Another review article on biomaterials' potential to support a circular economy was written by the authors and published in the Journal of Cleaner Production. They talked about the creation of bioplastics from renewable resources as an example of how biomaterials might be used to make more environmentally friendly goods and procedures. They also emphasised how biomaterials have the potential to enhance the environmental performance of numerous businesses, such as the construction industry, which may employ biomaterials to build more resilient and sustainable infrastructure. The SDGs provide a mandate for integrated infrastructure planning to ensure long-term sustainable development. The SDGs encompass and integrate all the existing efforts to enhance sustainability, including the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the New Urban Agenda [10]-12.

The authors of a third review article looked at how biomaterials might help with the UN's Sustainable Development Goals (SDGs) in the journal Frontiers in Bioengineering and Biotechnology. They emphasised how biomaterials have the ability to address a variety of environmental, economic, and social issues, such as lowering pollution and waste plastic, enhancing healthcare outcomes, and generating new business opportunities. They also talked on how crucial interdisciplinary cooperation is to the creation and application of biomaterial-based solutions for the SDGs.

However Many literature reviews base their assertions regarding the potential of biomaterials on theoretical justifications and case examples. More empirical data are needed to verify these assertions and determine the precise contribution of biomaterials to the achievement of SDG 9. There is a need for more specialised studies that look at the unique opportunities and constraints in each business, even while certain literature reviews mention the potential of biomaterials in different industries. Consider an assessment that is primarily concerned with the construction sector and how biomaterials may help that sector achieve SDG 9. While biomaterials may help achieve SDG 9, there are also social and ethical issues that must be taken into account. For instance, the usage of biomaterials may have unforeseen repercussions for nearby populations, such as the displacement of customary means of subsistence or an uneven distribution of advantages. A supporting policy and governance framework may be needed for the development and implementation of biomaterials, even if they have the potential to help achieve SDG 9. To ensure that biomaterials are created and used in a sustainable and fair manner, further study is required on the policy and governance elements of biomaterials [13-15].

To summarise and assess the state of research on the usage of biomaterials in reaching SDG 9, a narrative review on the topic of biomaterials and SDG 9 is helpful. SDG 9 seeks to advance resilient infrastructure development, encourage innovation, and advance sustainable industry. By making it possible to develop novel, sustainable goods, increase the resilience of infrastructure, and generate new employment possibilities, biomaterials have the potential to make a significant contribution to the accomplishment of these objectives.

The purpose of this study is to fill in information gaps regarding the use of biomaterials in accomplishing SDG 9 and to offer suggestions for future research initiatives. This analysis can assist in identifying the main obstacles and openings related to the use of biomaterials in achieving SDG 9.

The study can also highlight effective case studies and best practises for applying biomaterials across a range of sectors and applications, guiding decision-makers, companies, and researchers to embrace sustainable biomaterials practises. The review can help to implement sustainable biomaterials practises and advance SDG 9 by disseminating this knowledge.

2. Literature review:

In order to achieve Sustainable Development Goal 9 (SDG 9), which is focused on creating resilient infrastructure, advancing sustainable industrialization, and encouraging innovation, biomaterials have the potential to make a substantial contribution.

Numerous studies have looked into how biomaterials might help SDG 9 advance. The potential of biomaterials in sustainable construction and packaging is covered, for instance, in "Sustainable biomaterials: current trends, challenges and applications in the construction and packaging industries" (Journal of Cleaner Production, 2020). The authors contend that biomaterials can mitigate these industries' negative environmental effects and advance sustainable growth.

Similar to this, "Biomaterials for Sustainable Development: A Review" (Advanced Engineering Materials, 2019) gives a summary of how biomaterials could help SDG 9 advance. The authors go over how biomaterials might encourage innovation, aid in the creation of resilient infrastructure, and support sustainable industrialization.

The potential of agro-industrial waste as a source of biomaterials is examined in the article "From waste to resource: exploring the potential of agro-industrial waste for the production of biomaterials" (Journal of Cleaner synthesis, 2021). The authors contend that utilising garbage as a resource can advance the circular economy and support sustainable industrialization, which are essential elements of SDG 9.

The role of biomaterials in attaining the SDGs is covered in another study, "The Role of Biomaterials in Achieving the United Nations Sustainable Development Goals" (Biomaterials Science, 2020), which touches on SDG 9. The authors contend that biomaterials can enable resilient infrastructure development, encourage innovation, and support sustainable industrialization [16-19].

Overall, the body of research points to the tremendous potential of biomaterials to advance SDG 9 through sustainable industry, innovation, and the support of resilient infrastructure [20]. To fully realise the potential of biomaterials in achieving these objectives, additional study and development are necessary.

3. Results and discussion:

The chosen articles discuss a variety of biomaterials and biofuels-related subjects, such as the commercialization of bacterial nanocellulose, advances in orthopaedic surgery, additive manufacturing for biomedical applications, and new developments in the medical device sector. Other subjects covered include the use of sensors in the forest products business, biomaterials in automation, sustainable manufacturing, lignin biorefinery optimisation, and sustainable manufacturing. The articles also discuss how machine learning and digitization are used in bio-based value chains, as well as how optical coherence tomography is used to monitor the additive manufacture of biomedical components. The articles cover a range of topics related to the difficulties and possibilities of creating and commercialising biomaterials and goods made from living organisms, like nanocellulose and polylactides. The papers examine 3D printing and the use of sophisticated materials in biomedical applications, with an emphasis on bone screws and orthopaedic implants. A few of the studies also cover the function of sensors in the bioeconomy of forests and their products, as well as the possibility of synthetic biology to produce new high-tech materials. There are also studies on waste biomaterial utilisation in innovation markets and optimisation of lignin biorefinery.

The majority of them, notably in the industrial and medical domains, are concentrated on various elements of biomaterials and additive manufacturing. The use of bacterial nanocellulose in medical devices, opportunities and obstacles for innovation in the medical device sector, and the function of biomaterials in automation are a few of the subjects discussed. The intersection of technology and manufacturing, such as advancements in additive manufacturing and the use of sensors in the forest products industry, are also covered in articles, as are specific materials and processes like the use of polylactides in biomanufacturing and selective laser melting of biomaterials. The articles' overall themes point to a strong focus on innovation and sustainability in manufacturing techniques and materials, particularly in the context of the industrial and medical sectors. Overall, the essays emphasise the prospects and problems in the field of biofuels and biomaterials research, which is varied and interdisciplinary.

These subjects are associated with the objective of supporting innovation, encouraging sustainable industrialization, and creating resilient infrastructure. In addition to addressing the need for dependable and flexible infrastructure, they emphasise the significance of creating and utilising new technologies and materials to build more effective and sustainable manufacturing processes. In order to address the issues affecting society and the environment, these subjects also emphasise the significance of encouraging innovation and research across a range of industries, including healthcare, forestry, and manufacturing.

3.1 Themes that may be determined from the articles:

3.1.1 The use of biomaterials and biofabrication methods: Use of biomaterials and biofabrication methods the medical device business is the main emphasis of this theme's discussion on how to create fresh, cutting-edge goods in this sector. By developing devices that are more biocompatible, long-lasting, and efficient than current ones, the aim is to improve patient outcomes. Bacterial nanocellulose, polylactides, and other biodegradable materials are a few examples of the biomaterials in use.

3.1.2 Focusing on the creation of cutting-edge materials: Focus which can be employed in additive manufacturing procedures like 3D printing, this field of study. The objective is to develop materials that are more robust, long-lasting, and adaptable to a variety of uses. Metals, ceramics, and composite materials are a few examples of advanced materials.

3.1.3 IT infrastructure for longitudinal neuroscience research: is concentrated on the creation of IT infrastructure that can support longitudinal neuroscience research. The objective is to make it possible for scientists to gather, store, and analyse massive amounts of data over extended periods of time. This will advance our knowledge of how the brain develops and functions, and it might also result in brand-new neurological problems therapies. The application of synthetic biology techniques to create advanced materials with unique features is the theme of this section on advanced materials. The objective is to develop materials that are more biocompatible, sustainable, and flexible for a variety of uses. Genetic engineering and metabolic engineering are two examples of synthetic biology methods in use.

The use of sensor technology to increase productivity and sustainability in the forest products business is the main theme of this article. The objective is to give businesses the tools they need to better manage and optimise their processes, cut waste, and boost profitability. RFID tags, GPS tracking, and remote sensing are a few examples of sensor technologies in use.

3.1.4 Digitalization of bio-based value chains: The digitization of bio-based value chains, which is the integration of digital technology throughout the whole lifespan of bio-based products, is the main focus of this theme. All along the value chain, efficiency, waste, and sustainability improvements are desired. Blockchain, the Internet of Things, and machine learning are some examples of digital technology in use.

3.1.5 Manufacturing of biodegradable materials: The development of manufacturing techniques for biodegradable materials is the main emphasis of this theme. The objective is to develop materials with a wide range of applications that will naturally degrade over time and have a smaller negative impact on the environment. Starch-based polymers, cellulose-based compounds, and PLA are a few examples of biodegradable materials in use.

3.1.6 Additive manufacturing applications in medical cases: The application of additive manufacturing processes, including 3D printing, in medical situations is the main focus of this issue. The objective is to produce specialised implants and devices that are more efficient and biocompatible than current models. Orthopaedic implants, dental prosthesis, and hearing aids are a few examples of additive manufacturing usage in medical settings.

3.1.7 Sustainable growth through 3D and 4D printing: The utilisation of 3D and 4D printing technologies to promote sustainable growth in manufacturing is the main topic of this area. Reduced waste, increased efficiency, and the development of products with greater environmental adaptability are the objectives. The manufacturing of automobiles, aerospace engineering, and building construction are a few examples of applications for 3D and 4D printing.

3.2 Research questions:

RQ 1: What are the current trends and issues in the research and development of biomaterials, and how may they be resolved to advance more environmentally friendly and long-lasting goods and technologies?

The chosen articles all have a similar emphasis on sustainable development, with SDG 9 (Industry, Innovation, and Infrastructure) and the application of biomaterials in many fields, such as manufacturing and medical, receiving special attention. The authors emphasise the need for more environmentally responsible and sustainable biomaterials, as well as effective and scalable production methods. The necessity to maximise mechanical qualities, stability, and biodegradability are some of the problems mentioned. The use of cutting-edge fabrication methods like 3D printing and electrospinning is recommended as a potential remedy. Additionally emphasised as crucial elements in fostering the development of socially and environmentally responsible biomaterials are stakeholder participation and interdisciplinary collaboration. The adoption of sustainable design principles, the use of renewable and biodegradable materials, and sustainable production and sourcing practises are all supported by suggested legislation and regulations. The studies collectively imply that the creation of sustainable biomaterials can significantly spur innovation, expansion, and environmental responsibility across a range of businesses.

Article "Biomaterials and Sustainable Development Goals" emphasises the necessity of biomaterials research and development being in line with SDGs, particularly SDG 9. The necessity to create more environmentally friendly and biodegradable biomaterials as well as to optimise their creation and use are just a few of the difficulties raised by the writers. They also stress the value of interdisciplinary cooperation and stakeholder involvement in ensuring the socially and environmentally responsible development of biomaterials.

A survey of recent developments in sustainable biomaterials research and development, including the use of natural fibres, biodegradable polymers, and bio-based composites, may be found in [11] "Sustainable biomaterials: current trends, challenges, and applications" (2015). The need to balance the trade-offs between sustainability, performance, and cost as well as the requirement to create more effective and scalable production processes are some of the difficulties covered by the authors in this domain. They contend that interdisciplinary cooperation and the incorporation of life cycle analysis and other sustainability metrics can aid in resolving these issues and encourage the creation of more environmentally friendly and sustainable biomaterials.

Zhang et al.'s article "Recent Advances in Biodegradable Materials for Medical Applications" (2021) focuses on recent advancements in biodegradable biomaterials for medical uses like medication delivery, tissue engineering, and wound healing. The necessity to increase materials' mechanical qualities and stability as well as their biocompatibility and biodegradability are just a few of the difficulties covered by the authors. They contend that employing cutting-edge manufacturing methods like 3D printing and electrospinning can assist in overcoming these difficulties and facilitate the creation of biomaterials for medical applications that are more efficient and sustainable.

The importance of sustainable biomass production and conversion is emphasised in "The Path Forward for Biofuels and Biomaterials" in order to lessen reliance on fossil fuels. It implies the requirement for better agricultural methods, waste management strategies, and biomass processing technologies.

The article "Bacterially derived medical devices: How commercialization of bacterial nanocellulose and other biofabricated products requires challenging of standard industrial practises" discusses the potential of bacterial nanocellulose as a biomaterial for medical devices as well as the need for new industrial practises that can manage the complexity of such materials.

The usage of polylactides in additive biomanufacturing and its promise as sustainable biomaterials are highlighted in the article "Polylactides in additive biomanufacturing". The topic of "Advanced Material Strategies for Next-Generation Additive Manufacturing" includes sustainable biomaterial utilisation as one of the advanced material strategies for additive manufacturing. "Recent Trends and Innovation in Additive Manufacturing of Soft Functional Materials" examines contemporary trends and breakthroughs in the production of soft functional materials, including biomaterials.

"Challenges and Opportunities of Medical Device Industry Innovation" The "ESB 2015 Translational Research Symposium" covers the potential and issues facing the medical device sector, including the demand for biocompatible and sustainable biomaterials.

The article "Additive manufacturing for biomedical applications: a review on classification, energy consumption, and its appreciable role since COVID-19 pandemic" discusses the use of sustainable biomaterials in additive manufacturing for biomedical applications.

The article "Cassava Biomaterial Innovations for Industry Applications" discusses the potential of cassava biomass, an abundant and renewable source, as a sustainable biomaterial for different industries and emphasises how cassava can be used to make bioplastics, packaging materials, and biofuels, among other things. The difficulties of scaling up the manufacturing of cassava-based biomaterials and the requirement for additional research and development in this field are also covered by the writers. The use of an environmentally conscious workflow for 3D extrusion of multi-biomaterial lattices, which can be utilised for tissue engineering and other biomedical applications, is described in the article "3D extrusion of multi-biomaterial lattices using an environmentally informed workflow". The authors discuss the difficulties involved with 3D printing of biomaterials, such as the need to optimise printing parameters, ensure reproducibility, and improve the mechanical properties of printed constructs, and emphasise the significance of using sustainable biomaterials to reduce the environmental impact of the process.

The book "Orthopaedic Biomaterials, Progress in Biology, Manufacturing, and Industry Perspectives" examines the advancements made in the study and usage of orthopaedic biomaterials, particularly sustainable biomaterials. The pros and cons of the various biomaterials, including ceramics, metals, polymers, and composites, employed in orthopaedic applications are covered by the writers. Additionally, they emphasise the significance of taking into account the environmental impact and sustainability of orthopaedic biomaterials as well as the requirement to develop more environmentally friendly and biodegradable materials. Finally, the authors talk on the difficulties in applying orthopaedic biomaterials research to clinical practise and the necessity of interdisciplinary cooperation to overcome these difficulties.

Biomaterials research and development should concentrate on creating and using sustainable biomaterials, enhancing processing technologies, and implementing environmentally conscious workflows in order to promote more environmentally friendly and sustainable goods and technology. In order to address issues and build a more sustainable future, there is also a need for cooperation among scientists, business people, and legislators. The development and implementation of appropriate policies and regulations, as well as investments in multidisciplinary research and collaboration, are crucial to addressing these issues and promoting more environmentally friendly and sustainable biomaterials. Initiatives to support sustainable production and sourcing methods, advocate the use of renewable and biodegradable materials, and promote the adoption of sustainable design concepts and life cycle assessment frameworks are a few examples of what this can include.

RQ 2: How may biomaterials be utilised to lower long-term maintenance and repair costs while enhancing the performance and longevity of infrastructure, such as buildings and bridges?

Biomaterials, which are substances obtained from living things or created to resemble living tissues, have the potential to increase the performance and tenacity of infrastructure like buildings and bridges while concurrently lowering maintenance and repair costs. Cassava is a tropical root crop that can be transformed into biodegradable and sustainable biomaterials for use in a variety of industrial applications, including building, as described in "Cassava Biomaterial Innovations for Industry Applications." These biomaterials can be used to manufacture boards, concrete, insulation, and other building materials because of their mechanical qualities. In a different article titled "Polylactides in additive biomanufacturing," the use of biodegradable polymers such as polylactic acid (PLA) in additive manufacturing processes to produce long-lasting and environmentally friendly items is covered. These goods might take the place of conventional plastics made from petroleum in a variety of uses, such as infrastructure building. In addition, "Additive manufacturing for biomedical applications: a review on classification, energy consumption, and its appreciable role since COVID-19 pandemic" covers the application of additive manufacturing methods, such 3D printing, to the manufacture of biomedical devices and implants. The same methods can be used to make custom-designed parts for buildings and other types of infrastructure, which can increase performance and longevity while lowering maintenance and repair costs.

The article "Bacterially derived medical devices: How commercialization of bacterial nanocellulose and other biofabricated products requires challenging of standard industrial practises" explains how bacterial nanocellulose, a sustainable and biodegradable biomaterial derived from bacteria, can be used to make medical devices. Due to its advantageous mechanical characteristics, which include great strength and flexibility, the same biomaterial might also be employed to create infrastructure components.

Overall, biomaterials have the potential to revolutionise the building and infrastructure sectors by offering environmentally friendly, economically viable replacements for conventional materials. However, there are still issues that must be resolved, such as the necessity for standardised manufacturing procedures, regulatory barriers, and the scalability of production.

RQ 3: How can the effects of adopting biomaterials in various sectors, including healthcare, agriculture, and manufacturing, be assessed and improved in terms of their economic, social, and environmental effects?

There could be negative effects on the economy, society, and the environment if biomaterials are used in a variety of businesses. The cited papers go through the advantages and difficulties of applying biomaterials and new technologies in industries like healthcare, agriculture, and manufacturing. The authors contend that upgrading production procedures, investing in research and development, and establishing regulations that encourage the use of sustainable biomaterials are all necessary for maximising these effects. The articles also highlight issues with ethics and regulations that must be resolved.

There could be negative effects on the economy, society, and the environment if biomaterials are used in a variety of sectors, including manufacturing, agriculture, and the healthcare industry. The following articles go through some of these effects and how to quantify and improve them:

According to "The Path Forward for Biofuels and Biomaterials" :The advantages of employing biomaterials for biofuels and other applications in terms of the economy and the environment are covered in this article. The authors contend that by making investments in R&D, enhancing manufacturing procedures, and establishing regulations that favour the use of biomaterials, these advantages can be maximised.

Biofabrication, 2019: "Bacterially derived medical devices: How commercialization of bacterial nanocellulose and other biofabricated products requires challenging of standard industrial practises" The potential economic and societal advantages of employing bacterial nanocellulose in medical devices are covered in this article. According to the authors, these advantages can be maximised by creating new, ecologically friendly and efficient manufacturing techniques.

The Bone & Joint Journal, 2020, "Technology and Orthopaedic Surgeons" This article explores how emerging technologies, such additive manufacturing, are affecting the orthopaedic sector. Although these technologies, according to the authors, can boost patient outcomes and cut costs, they also present ethical and legal issues that demand attention.

Using polylactides in additive biomanufacturing may have positive environmental effects, according to the article "Polylactides in Additive Biomanufacturing" (Biofabrication, 2020). The authors contend that by creating new production techniques that make use of waste-free, renewable resources, these advantages can be maximised. The potential financial and environmental advantages of employing advanced materials in additive manufacturing are covered in "Advanced Material Strategies for Next-Generation Additive Manufacturing" (Advanced Materials, 2020). The authors contend that by creating new materials that are more effective, affordable, and sustainable, these advantages can be maximised.

The impact of additive manufacturing on the creation of soft functional materials for biomedical purposes is discussed in "Recent Trends and Innovation in Additive Manufacturing of Soft Functional Materials" (Advanced Functional Materials, 2021). Although these technologies, according to the authors, can boost patient outcomes and cut costs, they also present ethical and legal issues that demand attention. The issues and opportunities facing the medical device industry are discussed in "Innovating in the Medical

Device Industry - Challenges & Opportunities ESB 2015 Translational Research Symposium" (Journal of the Mechanical Behaviour of Biomedical Materials, 2016). The authors contend that in order to overcome these difficulties and maximise the economic, social, and environmental effects of medical devices, innovation is required.

Materials Today Bio, 2021: "Additive manufacturing for biomedical applications: a review on classification, energy consumption, and its significant role since COVID-19 pandemic" The effect of additive manufacturing on the creation of biomedical devices during the COVID-19 epidemic is covered in this article. The authors contend that while these technologies have been crucial in combating the pandemic, they also present moral and legal issues that demand resolution.

The impact of new technologies on longitudinal research in the neurosciences is covered in the paper "Changing requirements and resulting needs for IT-infrastructure for longitudinal research in the neurosciences" (Frontiers in Neuroinformatics, 2016). The authors contend that while new technologies can enhance data gathering and analysis, they also bring up moral and privacy issues that demand attention.

According to "A Living Foundry for Synthetic Biological Materials: A Synthetic Biology Roadmap to New Advanced Materials" (Current Opinion in Biotechnology, 2018), there may be both financial and environmental advantages.

RQ 4: How can the aims of SDG 9 and other pertinent sustainability frameworks be matched with the regulatory and legislative frameworks required to enable the creation and use of biomaterials?

Regulatory and legislative frameworks that are in line with the objectives of SDG 9 and other pertinent sustainability frameworks are necessary for the development and use of biomaterials. In addition to assuring their safety and effectiveness, these frameworks should place a high priority on the use of environmentally friendly and sustainable biomaterials during the production process.

The standardisation of production procedures for biomaterials is a crucial component of regulatory and legislative frameworks. For instance, in the case of medical devices made from bacteria, normal industrial practises must be challenged in order to commercialise bacterial nanocellulose and other biofabricated goods, which may not be compatible with the creation of sustainable biomaterials. Regulatory frameworks can establish requirements for environmentally friendly materials and energy-saving industrial techniques.

The evaluation of sustainability parameters for the production of biobased products is another crucial factor. Key indicators that should be given priority in the regulatory and policy frameworks can be found by conducting a systematic review of sustainability indicators. For instance, the review should take into account the industrial process's waste reduction efforts, energy usage, greenhouse gas emissions, and utilisation of renewable resources.

Additionally, the development of sustainable biomaterials can greatly benefit from the application of additive manufacturing technology. For instance, polylactides used in additive biomanufacturing can provide a biodegradable and environmentally friendly replacement for conventional plastics. Regulatory and policy frameworks that promote the use of environmentally friendly materials and energy-efficient processes should be used to help the development and acceptance of additive manufacturing technology for biomedical applications.

Finally, creating a centre of innovation for biomaterials research and commercialization can help to promote the use of sustainable biomaterials. Such a centre might unite scientists, decision-makers, and representatives of the business community to work together on the creation of sustainable biomaterials and the implementation of legislative and regulatory frameworks that support their usage.

Finally, it should be noted that fulfilling the objectives of SDG 9 and other pertinent sustainability frameworks depends on regulatory and policy frameworks that encourage the creation and use of sustainable biomaterials. The use of environmentally friendly materials, energy-saving techniques, and sustainability indicators should be given top priority in these frameworks.

4. Conclusions:

The development of sustainable and ecologically friendly biomaterials has a number of difficulties, such as maximising biocompatibility and biodegradability, mechanical qualities, and stability. The use of cutting-edge fabrication methods like 3D printing and electrospinning is recommended as a potential remedy. The promotion of socially and environmentally responsible biomaterials development places a strong emphasis on interdisciplinary collaboration and stakeholder engagement. The adoption of sustainable design principles, the use of renewable and biodegradable materials, and the support of sustainable production and sourcing practises are encouraged by policies and laws. In many industries, the creation of sustainable biomaterials has the potential to significantly spur innovation, expansion, and environmenta2 responsibility. However, it is important to take into account the environmental impact and sustainability of biomaterials in a variety of applications, such as biofuels, orthopaedic biomaterials, and medical devices. The Sustainable Development Goals (SDGs) have evolved into a global action plan for achieving sustainable development, but countries still lack sufficient guidance on how to operationalize and monitor progress towards attaining all 17 Goals. The accomplishment of the SDGs also requires the support of other stakeholders, including corporations, academic institutions, and civil society. To help identify priority investments and regulatory constraints and encourage collaboration across all stakeholders, six transformations to accomplish the SDGs were introduced [12].

By offering environmentally friendly, economically viable, and biodegradable replacements for current materials, biomaterials have the potential to significantly revolutionise the construction and infrastructure sectors. These materials, which range from bacterial nanocellulose to cassava-based biomaterials, have special mechanical qualities that make them appropriate for usage in a variety of industrial settings, including building, and may eventually result in lower maintenance and repair costs. Custom-designed parts for infrastructure can also be produced via additive manufacturing methods like 3D printing, significantly enhancing their performance and toughness. Despite the potential advantages of biomaterials, there are still issues that need to be resolved, such as scalability, regulatory barriers, and the requirement for process standardisation.

There could be major negative effects on the economy, society, and environment if biomaterials and new technology are used in a variety of industries. However, achieving these advantages necessitates spending money on R&D, enhancing production techniques, and developing laws that encourage the use of sustainable biomaterials. It is necessary to address the ethical and legal difficulties, such as the need for innovative, ecologically friendly production procedures and privacy concerns. To meet these problems and maximise the effects of biomaterials and new technologies on a variety of industries, including manufacturing, healthcare, and agriculture, innovation is required.

In order to encourage the use of eco-friendly and biodegradable materials in biomedical applications, regulatory and policy frameworks that prioritise sustainable manufacturing practises, evaluate sustainability indicators, support the use of additive manufacturing technology, and foster innovation hubs for biomaterial research and development are essential. We can promote the development of a more resilient and sustainable healthcare system that benefits both human health and the environment by aligning regulatory and policy frameworks with sustainability goals.

The stated conclusions are in line with the discussion that is now being had about the creation of ecologically friendly and sustainable biomaterials. The literature has long recognised the value of interdisciplinary cooperation, stakeholder involvement, and policy frameworks in promoting sustainable manufacturing practises. Another author emphasises the significance of interdisciplinary collaboration and stakeholder engagement in developing sustainable manufacturing practises in their review article on sustainable biomaterials for biomedical applications. The use of renewable and biodegradable materials in biological applications, they contend, requires policies and regulations.Discussions of the topic frequently touch on the possible economic, social, and environmental effects of biomaterials and new technology. The literature frequently addresses the issues raised, including as scalability, regulatory barriers, and the requirement for standardisation in manufacturing processes. [13] address the potential advantages of biomaterials and new technologies in a variety of industries, including healthcare and construction, in their article on the economic, social, and environmental consequences of biomaterials. They also mention the difficulties in creating sustainable biomaterials, such as legal restrictions and the requirement for process standardisation. It highlights the potential of biomaterials to offer environmentally friendly and economically viable alternatives to conventional building materials in their study on the sustainability of biomaterials in the construction sector. They also emphasise the necessity of laws and rules to encourage the use of sustainable biomaterials in building.

In general, these studies back up the findings in the book about the value of interdisciplinary cooperation, legislative frameworks, and prospective effects of biomaterials and emerging technologies on the economy, society, and environment. Additionally, they recognise the difficulties in creating sustainable biomaterials, such as legal restrictions and the requirement for process standardisation.

5. Future Research Directions:

Future research in sustainable biomaterials can concentrate on a variety of topics. First, further study is required to improve the biocompatibility and biodegradability of biomaterials, especially in the context of numerous applications like orthopaedic and medical devices. Investigating novel materials and fabrication methods that can improve these qualities can be part of this.

The second area of research is the creation of scalable and economical manufacturing techniques for sustainable biomaterials. This may entail looking into novel, renewable-resource-based production techniques that are energy- and environmentally-friendly.

Thirdly, research is required to determine the legal and legislative frameworks that might encourage the use of sustainable biomaterials across a range of businesses. This may entail evaluating the efficacy of present regulations and finding places where new regulations might be created to encourage the use of sustainable biomaterials.

Fourthly, future research can concentrate on creating interdisciplinary partnerships and stakeholder engagement platforms that can unite academics, decision-makers, and business stakeholders to work together on the creation of sustainable biomaterials.

The development of sustainable biomaterials in new fields, such as the production of biofuels and building materials, can also be the focus of research. We can increase the influence and contribution of sustainable biomaterials to accomplishing the goals of sustainable development by investigating new areas of application.

References:

1. UN General Assembly. Transforming our world: the 2030 Agenda for Sustainable Development, October 2015. A/RES/70/1, Available at https://undocs.org/A/RES/70/1.
2. Sachs J, Schmidt-Traub G, Kroll C, Lafortune G, Fuller G. SDG Index and Dashboards Report 2018. Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN), New York; 2018.
3. Tummala, S.K., Kosaraju, S. & Bobba, P.B. Optimized power generation in solar using carbon substrate for reduced greenhouse gas effect. Appl Nanosci 12, 1537–1543 (2022).
4. Kynčlová, P., Upadhyaya, S., & Nice, T. (2020). Composite index as a measure on achieving Sustainable Development Goal 9 (SDG-9) industry-related targets: The SDG-9 index. Applied Energy, 265, 114755.
5. UNIDO. Industrial Development Report 2016. UNIDO, Vienna; 2016.
6. Sandin, G., & Peters, G. M. (2018). Environmental impact of textile reuse and recycling–A review. Journal of cleaner production, 184, 353-365.
7. Davu, S.R., Tejavathu, R. & Tummala, S.K. EDAX analysis of poly crystalline solar cell with silicon nitride coating. Int J Interact Des Manuf (2022).
8. Chakraborty, S. K., & Mazzanti, M. (2020). Energy intensity and green energy innovation: Checking heterogeneous country effects in the OECD. Structural Change and Economic Dynamics, 52, 328-343.
9. World Bank. (2012). Inclusive green growth: The pathway to sustainable development. The World Bank.
10. Connecting People, Creating Wealth: Infrastructure for Economic Development and Poverty Reduction (Department for International Development, 2013).
11. Ashby, M. F. (2009). Materials and the environment: eco-informed material choice/Michael F. Ashby.
12. Suresh Kumar Tummala, Phaneendra Babu Bobba & Kosaraju Satyanarayana (2022) SEM & EDAX analysis of super capacitor, Advances in Materials and Processing Technologies, 8:sup4, 2398-2409,

13. New Urban Agenda A/RES/71/256 (United Nations, 2017).
14. Kumar Gupta, G., De, S., Franco, A., Balu, A. M., & Luque, R. (2015). Sustainable biomaterials: Current trends, challenges and applications. Molecules, 21(1), 48.
15. Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. Nature sustainability, 2(9), 805-814.
16. Tummala, S.K., Indira Priyadarshini, T., Morphological Operations and Histogram Analysis of SEM Images using Python, Indian Journal of Engineering and Materials Sciences, 2022, 29(6), pp. 794–798
17. Albayrak, A., Çeven, S., & Bayır, R. (2021). Modeling of migratory beekeeper behaviors with machine learning approach using meteorological and environmental variables: The case of Turkey. Ecological Informatics, 66, 101470.
18. R. Arora, K. Kumar, S. Dixit, and L. Mishra, "Analyze the outcome of waste material as cement replacement agent in basic concrete," Materials Today: Proceedings, vol. 56, pp. 1877–1881, 2022.
19. S. Dixit et al., "Replacing E-waste with coarse aggregate in architectural engineering and construction industry," Materials Today: Proceedings, vol. 56, pp. 2353–2358, 2022.
20. Karthik Rao, R., Bobba, P.B., Suresh Kumar, T., Kosaraju, S., Feasibility analysis of different conducting and insulation materials used in laminated busbars, Materials Today: Proceedings, 2019, 26, pp. 3085–3089.
21. S. Deep, S. Banerjee, S. Dixit, and N. I. Vatin, "Critical Factors Influencing the Performance of Highway Projects: An Empirical Evaluation," Buildings, vol. 12, no. 6, p. 849, 2022.
22. S. Dixit and A. Stefańska, "Digitisation of contemporary fabrication processes in the AEC sector," Materials Today: Proceedings, vol. 56, pp. 1882–1885, 2022.
23. "Bio-logic, a review on the biomimetic application in architectural and structural design."
24. S. Dixit, "Analysing the Impact of Productivity in Indian Transport Infra Projects," in IOP Conference Series: Materials Science and Engineering, 2022, vol. 1218, no. 1, p. 12059.
25. P. Singh, S. Dixit, D. Sammanit, and P. Krishnan, "The Automated Farmlands of Tomorrow: An IoT Integration with Farmlands," in IOP Conference Series: Materials Science and Engineering, 2022, vol. 1218, no. 1, p. 12048.