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Metaverse adoption as a cornerstone for sustainable healthcare firms in the industry 5.0 epoch

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Abstract

Purpose – This research looks into the revolutionary potential of Industry 5.0, healthcare, sustainability and the metaverse, with a focus on the transformation of healthcare firms through cutting-edge technologies such as artificial intelligence (AI) and Internet of Things (IoT). The study emphasizes the significance of sustainability, human-machine collaboration and Industry 5.0 in the development of a technologically advanced, inclusive and immersive healthcare system.

Design/methodology/approach – The study surveyed 354 medical professionals and used structural equation modeling (SEM) to investigate healthcare sustainability, Industry 5.0 and the metaverse, emphasizing the integration of modern technology while maintaining ethical issues.

Findings – The findings highlight Industry 5.0's and the metaverse's transformational potential in healthcare firms. The study finds that human centricity (HC) has only a minor direct impact on healthcare sustainability, whereas intelligent automation (IA) and innovation (INN) play important roles that are regulated by external factors.

Practical implications – Utilizing IA inside healthcare organizations can result in significant industrial advancements. However, these organizations must recognize the importance of moderating factors and attempt to find a balance between INN and thesev restraints.

Originality/value – This study makes a substantial contribution to the field by investigating the potential of Industry 5.0, healthcare, sustainability and the metaverse. It discusses how these advances can transform healthcare firms, with an emphasis on patient-centered treatment, environmental sustainability and data ethics. The study emphasizes the importance of having a thorough awareness of these trends and their implications for healthcare practices.

Keywords Healthcare firms, Sustainability, Human centricity, Intelligent automation, Innovation, Moderation effects, Patient-centered care, Human-machine interaction, Economic dimension, Environmental dimension, Social dimension, Industry 5.0, Metaverse, United Arab Emirates

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1. Introduction

The healthcare sector has seen a significant transition due to enterprise and information. Wearables, mobile health applications, telemedicine, electronic health records and health information technology have all helped to facilitate this transformation. This convergence of tools and technologies, known colloquially as "digital health," has resulted in a fundamental rethinking of healthcare delivery (Petersen, 2018). The term "digital health" describes the application of digital technology, including wearable sensors, health apps and mobile devices, to better patient outcomes, streamline the delivery of healthcare and make health management easier (Madanian *et al.*, 2023; Petersen, 2018). For instance, telemedicine, which gained popularity during the COVID-19 pandemic, was made possible by the development of digital health. Laksono and Darmawan (2021) in his study found that through video connections, telemedicine enables patients to communicate with their medical professionals and conduct consultations remotely. This improves accessibility especially for people living in distant places, while saving time and money. In essence digital health encourages a patient-centric strategy, giving people the tools to manage their health successfully. To proactively identify potential health risks, healthcare practitioners use data from wearables and health applications. Proactive treatment, early interventions and customized guidance are made possible by this individualized data. Better decision-making and remote monitoring support more efficient healthcare tactics that enhance patient outcomes and engagement.

The phrase "metaverse," which has only recently gained popularity among academics and observers of technology, first appeared in (Stephenson, 1994) book "Snow Crash." It was initially portrayed as a virtual reality (VR) environment that used the internet and augmented reality (AR) with the help of avatars and software agents (Joshua, 2017). Ahmad *et al.* (2022) studied that users can participate in immersive digital experiences, social interactions and transactions beyond online interactions in the metaverse, a virtual, networked realm that blends augmented reality, VR and the internet. Its relevance to digital health has grown significantly. According to Billah *et al.* (2023), the metaverse has been compared to an advanced form of the Internet that uses avatars, blockchain technology and VR headsets. Businesses and other entities have a lot of room to change how they operate and do business to better fit into the metaverse (Liu *et al.*, 2023). Billah *et al.* (2023) studies the integration of enterprises into metaverse is rising. The immersive digital experiences, augmented and VR that define the metaverse offer a game-changing platform for a number of industries including marketing, travel, hospitality and more. Due to the seamless blending of real and virtual worlds and numerous improvements to our experiences and interactions, future metaverse users will have the access to many opportunities (Mystakidis, 2022).

The most current development in industrial automation is known as Industry 5.0, and it is characterized by the incorporation of cutting-edge technologies like the Internet of Things (IoT), artificial intelligence (AI) and machine learning (ML) (Alpala *et al.*, 2022; Nahavandi, 2019). The next stage of industrial development, known as Industry 5.0, it emphasizes on strong cooperation and collaboration between workers/humans and machinery. It aims to improve productivity, creativity and overall industrial processes by fusing human abilities with cutting-edge technologies like robotics and AI (Ghobakhloo *et al.*, 2022). The production process's optimization is its primary goal. Human-machine collaboration is strongly emphasized in Industry 5.0 to establish a manufacturing environment that puts the importance of the human element first (Lu *et al.*, 2022). According to the European Union, Industry 5.0 envisions an industry beyond mere productivity and efficiency, emphasizing the sector's role and societal contributions (Dilibal and Tur, 2022). By utilizing connected medical devices and telemedicine, Industry 5.0 can potentially improve patient care and treatment in digital health. These technologies improve healthcare delivery by enabling remote patient monitoring and diagnosis. Industry 5.0 technologies could also improve the efficiency and effectiveness of healthcare systems. This is accomplished by automating administrative tasks and making real-time data analysis in decision-making possible (Kaur *et al.*, 2023; Settanni *et al.*, 2022). Such technological developments also simplify the supply chain for pharmaceutical and medical goods. Implementing smart factories can improve production efficiency, reduce waste and improve supply chain traceability and transparency.

The confluence of digital health, the metaverse and Industry 5.0 is completely changing the healthcare sector. Although wearables and telemedicine have made major strides in the field of digital health, there are still many unanswered questions about how Industry 5.0 and the metaverse may be seamlessly incorporated into healthcare systems. The integration has the potential to yield significant benefits, such as improved patient care, but further research is necessary to fully understand the elements that influence acceptance. For the seamless integration of these technologies into the healthcare sector, it becomes clear that three crucial areas need to get concentrated attention: user acceptance, infrastructure readiness and the resolution of ethical and regulatory issues. Research is still needed to close current gaps in the domains of the complex interactions between Industry 5.0 and the actualization of the metaverse's potential in healthcare. Considering these gaps our study focuses on the following objectives:

(1) Examine the possible advantages of incorporating the metaverse into healthcare, putting a focus on long-term performance enhancement that includes resource efficiency, environmental impact and patient well-being.

(2) Consider how user acceptance, infrastructure readiness and ethical considerations can be used to minimize the impact of Industry 5.0 technologies on long-term performance improvement in healthcare.

(3) Identify key adoption factors that affect the seamless incorporation of Industry 5.0 and the metaverse in healthcare, such as regulatory frameworks, technological infrastructure and stakeholder involvement.

By focusing on these study objectives, we hope to advance our understanding of how emerging technologies can revolutionize healthcare and offer practical suggestions for promoting inclusive, sustainable healthcare systems.

This article is organized as follows. Section 2, the Literature Review, explores critical summaries of Industry 4.0 and 5.0 and their applicability to the healthcare industry and sustainable performance in this field. Section 3, Research Methodology, describes the research strategy, the methods used to collect the data and the approaches used to analyze the data. The benefits of using the metaverse in healthcare, its possible impact on long-term performance, and its moderating effect regarding the fusion of Industry 5.0 technologies and performance enhancement are covered in Section 4. We analyze our results, highlight their ramifications and offer perceptions into theory and practice in Section 5. Following this, in Section 6, we evaluate our findings in the context of prior research and present recommendations for stakeholders, decision-makers and healthcare organizations. Lastly, Section 7 summarizes our primary findings, emphasizing their contribution to the field. While acknowledging the study's limitations, we suggest potential research directions for further exploration in this evolving domain.

2. Literature review

The metaverse creates a three-dimensional environment where people and things can travel, share and communicate by fusing physical reality and digital virtuality (Agarwal *et al.*, 2017; Lee, 2022). As technology develops, the metaverse is considered the next frontier beyond the internet and e-commerce. While in its early stage, the metaverse has much potential for many industries, including healthcare. It enables enterprises to design virtual environments where users communicate, coordinate and monitor tasks like acquiring information, offering services and buying and selling goods (Delgado, 2022). Nahavandi (2019) studied that correctly applying these technologies becomes increasingly important as the metaverse and Industry 5.0 technologies take off. Industry 5.0 is an evolution of industries that includes cutting-edge technology while strongly emphasizing social responsibility, sustainability and human empowerment. It tries to develop a business model that is more effective and fair. The literature on digital transformation has drawn attention to the potential harm some technologies may do to sustainability. Robotics and big data, for instance, can boost productivity, but they also risk eliminating jobs and increasing energy use (Song and Kook, 2022; Yong *et al.*, 2022).

Similarly, implementing Industry 4.0 technology may necessitate major adjustments to supply chains to solve environmental issues (Kumar *et al.*, 2024). Likewise, Deveci *et al.* (2023) found that, the metaverse has implications for both economic and environmental sustainability, such as reducing transportation emissions while affecting social connections and physical relationships. Because of this, it is crucial to design the metaverse in a way that respects human rights, working conditions, social integration and environmental sustainability and is consistent with Industry 5.0 ideals. Industry 5.0 is an embryonic notion without universally accepted defining pillars. Nonetheless, it revolves around a few significant ideas linked to its essence. These fundamental themes are as follows:

(1) Human Centricity: At the heart of Industry 5.0 the focus is on the intervention of humans in the production domain (Nahavandi, 2019). In contrast to the tendency to replace human labor with automation, Industry 5.0 attempts to combine sophisticated technologies with human skills. This connection empowers employees and increases their productivity. Industry 5.0 envisions humans and technology working together to create a peaceful coexistence that unlocks new dimensions of potential.

(2) Interconnectivity: Industry 5.0 depicts a manufacturing environment tightly intertwined with the internet's fabric. This interconnected web includes a slew of equipment, sensors and devices. This level of connectedness increases the production process's flexibility and agility. It also orchestrates a more efficient use of available resources (Fry and Egel, 2021).

(3) Intelligent Automation (Robotics and IoT): Industry 5.0 entails integrating state-of-art technology such as automation and AI into the production scene (Hines and Netland, 2022). When these technologies are adopted, a dramatic shift happens in the manufacturing process. Robotics deployment streamlines operations, while ML and AI promote adaptive learning mechanisms (Kaur *et al.*, 2022). This combination leads to an increase in efficiency and precision. The application of these technologies not only improves the finished product's quality but also results in significant waste savings. Furthermore, intelligent automation (IA) optimizes the manufacturing process by optimizing workflows and reducing errors, ultimately increasing total efficiency.

(4) Innovation (INN) (IoT, Big data analytics): Industry 5.0 relies on a pervasive culture of INN and continuous improvement. This distinguishing essence characterizes the fabric of Industry 5.0. Companies that embrace this paradigm do more than adopt new technology; they cultivate an environment that encourages experimentation with cutting-edge tools and processes (Adner and Kapoor, 2010; Jabeen *et al.*, 2023). They go on a road of continuous improvement, constantly looking for new ways to

better their operations. The core of Industry 5.0 is defined by the combination of forward-thinking technologies and an organizational mindset that values evolution.

In Healthcare 5.0, with incorporation of autonomation ideas in the delivery of services, is riding high on a wave of technological advancements led by the IoT, AI and big data. Many studies have been done on these transformative technologies, including those by Craig *et al.* (2021), Efendi *et al.* (2023), Shah *et al.* (2022) and Zwolak and Trout (1997). But as the healthcare sector moves towards digitalization, privacy and ethical concerns grow more pressing. Research by Green *et al.* (2017) indicates that the upkeep of the digital environment poses intricate challenges that emphasize the need for robust security measures to ensure patient well-being and data protection.

Green *et al.* (2017) presents a comprehensive introduction of foundational ideas such as AI, the IoT and 5G connectivity. These ideas are crucial in building high-speed data transmission networking mechanisms within healthcare facilities, ushering in a new era of healthcare philosophy (Wang and Alexander, 2019). The focus is improving fifth-generation (5G) communication, AI integration and IoT devices. This convergence is the driving factor behind advancing healthcare technologies, ultimately contributing to better health. Saraswat *et al.* (2022) describes a framework in tomography using advanced AI techniques. The framework contains an electrocardiogram (ECG) monitoring case study and measure validation. Real-world model implementation for various contexts highlights its utility in healthcare settings. A visionary proposal is introduced: a supersmart, sustainable healthcare system under the aegis of Society 5.0 (Tuppad and Patil, 2022). This system is designed with application of several latest digital technologies like Internet of things, AI, Cloud computing etc. Its purpose is to provide equal, dependable and optimal healthcare access to all members of society (Kumar, 2019). The conversation covers stakeholder responsibilities, significant technologies, data management approaches and ethical considerations, focusing on patient safety, data security and general well-being. AI-based algorithms have been highlighted as a transformational instrument capable of impacting urban health using massive data resources (Sapienza *et al.*, 2022). According to the report, countries that benefit from a holistic use of financial assets, technological resources and healthcare must know how to collaborate on comprehensive research in digital technologies. This strategy addresses the many issues that influence urban health, opening the way for more sustainable living conditions. The dominant trend in this domain reflects a strong emphasis on the technology features that drive Healthcare 5.0. Studies primarily focus on the several technologies that comprise the Healthcare 5.0 landscape, which are tightly connected with security and privacy concerns. This concentration, however, tends to ignore a range of additional difficulties that require addressing. These issues have multiple dimensions, including the initial high cost of new systems. Furthermore, the essential aspect of patient acceptability and successful adoption of emerging technologies necessitates careful study to ensure a smooth transition into the Healthcare 5.0 paradigm. Another critical aspect that frequently gets overlooked is the problem of integrating disparate technologies cohesively and ensuring their compatibility. As the landscape changes, these difficulties become increasingly important in the revolutionary journey towards Healthcare 5.0.

2.1 Exploring the essence of industry and healthcare 5.0

Industry 5.0 is a bit complex. Although it is widely regarded as the successor of Industry 4.0, consensus on its own qualities remains elusive. As a result perceptions and definitions of Industry 5.0 may range slightly among researchers and institutions. Furthermore the importance of Industry 5.0 focusing on human labor includes a subjective aspect allowing different points of view. While some see Industry 5.0 as a substantial departure, focusing on ingenuity of human intellect. Dominantly Industry 5.0 encompasses HC with inclusion of digital technologies and production systems (Adel, 2022). Unlike earlier industrial revolutions, Industry 5.0 places humans at the focus of manufacturing. This is performed in collaboration with cutting-edge technologies such as robotics and AI. One distinguishing feature of Industry 5.0 is the orchestration of a more flexible and adaptable manufacturing process capable of quickly responding to market dynamics and client requirements. This unique concept creates machines that work in tandem with human workers.

Industry 5.0 frees up human resources to focus on tasks that require their particular abilities and experience by assigning routine or hazardous work to robots. This strategic manufacturing approach increases productivity and strives to improve the working environment for human personnel. A growing recognition of the critical balance between technological advancement and the needs and aspirations of human workers emphasizes Industry 5.0's emphasis on HC. This evolving understanding reflects a larger, more inclusive vision of the future of employment. Sustainability is another crucial aspect of Industry 5.0 (Ghobakhloo *et al.*, 2022). This arises from its desire to create an environmentally conscientious and sustainable manufacturing ecosystem. This ecosystem strives to increase efficiency and productivity while reducing carbon emissions and waste. Industry 5.0 has been methodically built to embrace sustainable approaches and technologies, including using concepts of circular economy and renewable energy integrating advanced analytics and ML. This coordinated effort optimizes resource allocation and reduces waste, aligning Industry 5.0 with environmentally responsible practices. This emphasis various aspect of sustainability indicates the growing requirement to balance economic success and environmental preservation and the development of a more ethical and accountable industrial process. The goal is to create a vision of the future of employment that is both sustainable and just. However, the world of Industry 5.0 faces a challenge: its vague and heterogeneous interpretation across organizations and nations impedes standard R&D advancement.

As the definition of Industry 5.0 continues to be a source of debate and disagreement, it is hoped that this discussion will eventually lead to a more appropriate and deliberated concept of this evolving idea. Even in its infancy, "Healthcare 5.0" is widely recognized as the subsequent development in health systems (Vermeulen and Grobbelaar, 2022). Healthcare 5.0 will prioritize personalized, preventive and participative care, utilizing revolutionary technologies to improve customer satisfaction and overall health (Halim *et al.*, 2022). The emphasis on actively allowing people to participate in health management is central to Healthcare 5.0. This paradigm goes beyond traditional techniques focusing primarily on treating illnesses and diseases, instead emphasizing holistic well-being and general health promotion. Healthcare 5.0 proposes a holistic healthcare framework promoting medical issues, patient engagement, personalized prevention and greater wellness.

2.2 Sustainability in healthcare

Sustainability in Healthcare needs an overarching approach to healthcare provisioning that it considers the interplay of elements of sustainability variables. This comprehensive viewpoint recognizes that achieving sustainability in the context of Healthcare 5.0 includes addressing medical concerns and broader societal, economic and ecological considerations.

(1) Resource Efficiency: The introduction of Industry 5.0 technologies favors various ecologically sustainable indicators, most notably resource efficiency and emission reduction. These sustainability results are frequently a result of the broader goal of increasing productivity (Rejeb *et al.*, 2022). Stakeholders have a critical role in Industry 5.0, as they are essential to the driving force behind this paradigm—societal needs. Industry 5.0 approaches its three sustainability pillars in a balanced manner, aiming to achieve a bi-directional balance between financial advancement and the

preservation of values pertaining to socio-economic aspects. The acknowledgment that stakeholder involvement and participation are critical in controlling and managing the digital industrial revolution is central to the Industry 5.0 agenda (Chonsalasin *et al.*, 2020). This accolade emphasizes the importance of stakeholder involvement in achieving Industry 5.0's overarching sustainability goals. Industry 5.0 technologies such as the IoT and AI have the potential to optimize resource utilization and reduce waste in healthcare settings. Healthcare facilities, for example, can use smart sensors and networked equipment to monitor and analyze energy consumption, water consumption and waste generation within hospitals and clinics. With real-time tracking, facility managers can discover inefficiencies and apply strategic initiatives to reduce resource use. Medical operations can precisely observe their sustainability habits with tools such as AI based sensing and networked technologies. This data-driven approach equips healthcare practitioners with the ability to discover flaws and execute methods to reduce resource use. These systems may dynamically modify lighting levels based on occupancy and natural light availability, resulting in more efficient energy usage in healthcare settings.

(2) Automation: Industry 5.0 emphasizes the importance of automation for enhancing usage and waste reduction. This approach extends to healthcare delivery, where robotic process automation (RPA) and AI automate regular patient registration, appointment scheduling and invoicing. Adopting this technology increases production and lowers errors and resource squandering (Dear, 2022). Furthermore, in healthcare, Industry 5.0 technologies such as AI and ML are critical. They provide for the early detection and diagnosis of problems, allowing for predictive maintenance. By anticipating problems, the need for emergency repairs is reduced, lowering the costs and resource depletion that are frequently associated with emergency interventions. In keeping with Industry 5.0 principles, the strategy emphasizes sustainable production practices and the use of environmentally friendly resources (Elizabeth *et al.*, 2015). The incorporation of efficient and ecologically sensitive components in medical equipment and supplies, as well as the integration of sustainable practices within healthcare facilities, can be advanced to delivering the services. The use of Industry 5.0 technologies enables analysis of big data, allowing detecting the patterns and trends in resource utilization. Using this data-driven approach, healthcare organizations can identify inefficiencies and design plans to optimize resource utilization. Industry 5.0 technologies are critical in achieving resource efficiency in the context of Healthcare 5.0. They accomplish this by increasing resource efficiency and efficacy, automating repetitive tasks through digitization, anticipating and addressing equipment breakdowns, incorporating sustainability and conducting analytics to find and correct inefficient operational zones. This integration is consistent with Industry 5.0's overall philosophy of supporting sustainable and holistic approaches to resource management in the healthcare industry.

(3) Patient-centered Care (PCC): Healthcare 5.0 emphasizes the need to take a service-centered approach to providing service, which includes adapting methods and diagnosing for the customized needs of individual patients. Minimizing unneeded tests and treatments helps reduce overall resource consumption in the healthcare sector (Maleka and Matli, 2022). Industry 5.0 technology, such as video conferencing and remote monitoring, enables patients to obtain medical care in remote and rural places, effectively reducing the need for travel. This improves healthcare access and minimizes travel-related carbon emissions' environmental impact. Industry 5.0 technologies

improve resource efficiency through a variety of techniques. EHRs provide the centralized and safe storage of patient information, allowing healthcare practitioners to access comprehensive patient data from any location (Maleka and Matli, 2022; Thomason, 2021). This simplifies care coordination and lowers unnecessary testing, treatments and waste. Wearable devices such as smartwatches and fitness trackers provide real-time health data and feedback, allowing patients to manage their health more effectively. This valuable data supports healthcare providers in tailoring treatment approaches and improving patient outcomes.

(4) Human-Machine Interaction: Industry 5.0 strongly emphasizes collaboration between humans and robots, a philosophy that also applies to healthcare. Integrating Industry 5.0 technologies in healthcare promotes more efficient collaboration among healthcare experts, decreasing resource-intensive activities such as travel. Telemedicine and remote monitoring allow more efficient cooperation and communication among healthcare practitioners. In radiology, Industry 5.0 tools such as computer-aided diagnosis (CAD) help radiologists interpret medical pictures more accurately. This reduces the need for recurrent imaging and improves resource efficiency by reducing waste. Surgery with an aid of robots is an instance of Industry 5.0 technology that enables doctors to perform difficult procedures more precisely. This results in fewer resource-intensive interventions, which improves patient outcomes while reducing complications. AI and ML, cornerstones of Industry 5.0, are critical in analyzing patient data and forecasting adverse effects. This predictive capability helps healthcare personnel take preventative measures, preserving resources and enhancing patient experiences. The integration of wearable technologies and remote monitoring, both trademarks of Industry 5.0, allows for real-time patient health tracking, providing healthcare practitioners with immediate input. This early intervention potential reduces the need for resource-intensive measures, improving patient experiences.

Using AI and ML speeds up drug development, lowering the time, cost and environmental impact of generating new treatments. Human-machine collaboration within Healthcare 5.0, powered by Industry 5.0 technologies, contributes to sustainability by boosting accuracy, minimizing bad outcomes, improving patient well-being and reducing resource-intensive interventions. Industry 5.0 technologies have an impact on the healthcare supply chain as well. Blockchain, for example, improves supply chain traceability and transparency, reducing waste and inefficiencies. IoT-enabled real-time tracking of medical supplies and equipment aids healthcare providers in optimizing inventory management, decreasing waste and improving efficiency.

Furthermore, digital technologies make data analysis easier for forecasting demand for medical goods, allowing for proactive inventory management. The adoption of technologies, such as additive manufacturing, enables on-demand production of medical usage products, decreasing the need for high inventory. This dynamic responsiveness adapts to changing patient needs and, as a result, improves patient outcomes. Using blockchain in the supply chain ensures the validity and origin of supplies, improving patient trust and increasing sustainability. By optimizing the healthcare providers can improve patient outcomes while ensuring healthcare delivery's long-term viability. Healthcare 5.0, defined by its patient-centric, personalized and preventive approach, is a disruptive force within the healthcare sector, linked with Industry 5.0's underlying concepts. This paradigm change has the capability to transform services, improve results and integrate smoothly into the larger Industry 5.0 framework. Healthcare 5.0 throws up tremendous prospects for a radical transformation in the healthcare environment by leveraging cutting-edge technologies such as AI, blockchain, big data analytics and robotics. Healthcare 5.0 introduces powerful diagnostic tools capable of early disease identification and complete disease management through the synergy of wearable sensors and AI algorithms. This progress in diagnostics empowers healthcare professionals and patients to make proactive efforts towards their health.

The study emphasizes the need to investigate Industry 5.0's ability to improve healthcare over the long run and the metaverse's function as a moderating factor. To achieve seamless integration, inform implementation strategies and realize the revolutionary potential of Industry 5.0 and the metaverse in healthcare, addressing concerns such as user acceptance, infrastructure and ethics is imperative. The way businesses function is changing due to the convergence of Industry 5.0 and the Metaverse. Meta, the old Facebook, aims to create a communal virtual environment for deeply engaging social interactions. With Microsoft Mesh, the company pioneers collaborative virtual experiences. Human-machine cooperation is transforming manufacturing in Industry 5.0; BMW and Audi are integrating smart technology to increase production. Digital twins and the metaverse are used in healthcare to provide individualized care and virtual training. Retail applications for augmented reality let buyers see products in actual environments. The dynamic growth of these ideas is still redefining human connections and industries.

In summary, Industry 5.0 and digital health through the metaverse seek to improve patient safety and outcomes by leveraging state-of-the-art technology to boost healthcare delivery efficacy and efficiency (Liang and Yeh, 2009; Lu *et al.*, 2022). However, integrating metaverse health applications successfully requires a full grasp of these cutting-edge technologies and their limits. Despite technological advancements, the healthcare industry's sustainable operation continues to pose a difficulty. By incorporating cutting-edge technologies, the shift from Industry 4.0 to Industry 5.0 presents chances to improve sustainable healthcare practices. However, there is still a dearth of research on the use of Industry 5.0 technologies and the metaverse as moderating elements for long-term performance improvement in the healthcare industry. Understanding the potential benefits and challenges of using the metaverse in healthcare is crucial for guiding successful implementation strategies and realizing the full potential of Industry 5.0 technology. The goal of this study is to examine the relationship between the adoption of metaverse technologies and the development of sustainable performance in the healthcare industry. One must carefully examine its benefits when considering integrating the metaverse in healthcare, particularly in the shift from Industry 4.0 to Industry 5.0. This involves assessing how using the metaverse can speed up this transition and enable a more seamless transition into the new era of Industry 5.0. Determining the potential long-term effects of the metaverse's application on performance within the healthcare industry also requires a thorough analysis. It's essential to consider factors like resource efficiency, environmental effects and overall patient experience improvement.

The combination of Industry 5.0 technologies, Metaverse adoption factors and sustainable performance measures gives a unique opportunity to drive INN, efficiency and sustainability in the developing environment of modern industries.

3. Model development

Healthcare 5.0 can elevate patient care, increase healthcare access and encourage more sustainable and efficient healthcare practices by integrating cutting-edge technologies—integration of Industry 5.0 Capability's emphasis on INN, HC, interconnection and IA (Table 1). Metaverse technology integration looks at resource efficiency and patient-centered treatment. Sustainable healthcare methods encompass environmental, social and economic sustainability. A transformative era is heralded by this convergence, which unites

Factor	Item	Description	Reference
Industry 5.0 Integration Capability	Human Centricity	The degree to which healthcare organizations prioritize human-centric approaches in their operations. It involves considering patients' and healthcare professionals' needs and preferences when designing processes, services and technologies	Wang *et al.* (2024) Adel (2022), Longo *et al.* (2020)
	Interconnectivity	Interconnectivity focuses on the integration and connectivity of various healthcare systems, devices and data sources. It assesses how effectively healthcare organizations can share and use data across different platforms and applications to improve patient care and efficiency	Chia (2022), Sverko *et al.* (2022)
	Intelligent Automation	Intelligent automation involves the use of advanced technologies like artificial intelligence (AI) and machine learning to automate repetitive tasks, enhance decision-making and improve efficiency in healthcare processes	Ghobakhloo *et al.* (2022), Kaur *et al.* (2023), Xu *et al.* (2019)
	Innovation	Innovation assesses a healthcare organization's ability to continually develop and adopt new technologies, practices and approaches to improve patient outcomes and streamline operations. It includes a willingness to embrace and invest in cutting-edge solutions	Abrahão *et al.* (2016), Özdemir and Hekim (2018), Zhan *et al.* (2022)
Metaverse Technology Integration	Resource Efficiency	Focuses on how healthcare organizations leverage metaverse technologies to optimize resource utilization. It includes considerations like virtual training, remote monitoring and resource allocation to improve efficiency and reduce waste	Harley (2022), Liu *et al.* (2022c)
	Patient-Centered Care	Involves using metaverse technologies to enhance the overall patient experience. It assesses how well healthcare organizations employ virtual care solutions, telehealth and patient engagement platforms to tailor care to individual patient needs	Lin and Zhao (2021), Wazid *et al.* (2022)
	Human-Machine Interaction	Human-machine interaction examines the integration of virtual or augmented reality technologies within healthcare settings. It evaluates the effectiveness of these technologies in facilitating communication, diagnosis and treatment between healthcare professionals and patients	Khalilzadeh *et al.* (2020), Longo *et al.* (2020), Wei *et al.* (2022)

(*continued*)

Table 1. Three critical aspects of healthcare sustainability practices

Factor	Item	Description	Reference
Healthcare Sustainable Practices	Environmental	The environmental subfactor evaluates the efforts made by healthcare organizations to reduce their environmental impact. This includes initiatives to lower energy consumption, minimize waste and adopt eco-friendly practices such as recycling and sustainable sourcing of materials	Nicolopoulou-Stamati *et al.* (2016), Shah *et al.* (2022)
	Social	Social sustainability assesses the healthcare organization's commitment to fostering a positive impact on the community and society at large. This may include initiatives related to community health outreach, social equity and addressing healthcare disparities	Pope *et al.* (2004), Shah *et al.* (2022)
	Economic	Economic sustainability focuses on the financial aspects of healthcare operations. It examines cost-saving measures, efficient resource allocation and strategies for providing high-quality care while managing healthcare costs effectively	Balcombe and De Leo (2022), Pope *et al.* (2004)

Table 1.

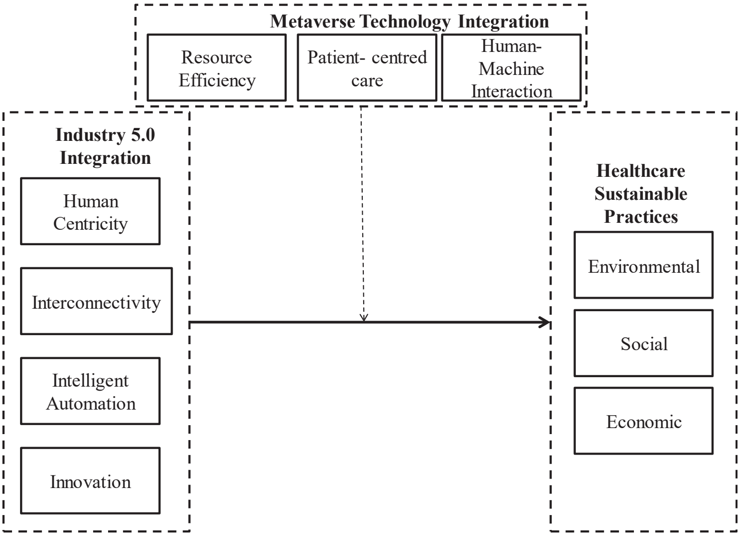
Source(s): Authors

technology, human-centric approaches and sustainable practices for future healthcare delivery. A brief summary entailing the three critical aspects of healthcare sustainability practices is depicted in Table 1.

The research model focuses on comprehending the connections between three critical aspects of healthcare sustainability practices (Table 1), Industry 5.0 integration capability and metaverse technology integration. The proposed model investigate the moderating relationships of metaverse technology integration between Industry 5.0 Integration Capability and various sustainability dimensions embodied by Healthcare Sustainable practices (Environmental, Social and Economic factors) (Dolgui and Ivanov, 2023) (see Figure 1).

3.1 Hypothesis development

Resource efficiency has a subtle influence on the complex relationship that exists between human-centric practices and environmental sustainability in healthcare. Setting human-centric approaches as a top priority affects resource optimization and may influence how successful environmental sustainability initiatives are. This demonstrates the complex interplay in the healthcare context between resource efficiency, HC and environmental concerns (Ji *et al.*, 2022). Hence according to Hypothesis 1a, the relationship between HC and the Environmental Factor is moderated by Resource Efficiency. This hypothesis states that the degree to which healthcare organizations priorities human-centric methods (HC) affects their capacity to optimize resource consumption (Resource Efficiency), which in turn affects their efforts to promote environmental sustainability (Environmental Factor) (Ji *et al.*, 2022). Similarly, Hypothesis 1b suggests that Resource Efficiency bridges the Social component and HC. It implies that emphasizing human-centric practices may impact resource efficiency,



Source(s): Authors own work

Figure 1. Conceptual framework

which may affect the social sustainability measures implemented by healthcare organizations. The concept of resource efficiency is extended to economic considerations in Hypothesis 1c, which shows that it moderates the link between HC and economic sustainability. According to this hypothesis, healthcare organizations prioritizing HC may also experience financial gains from using resources effectively.

H1a. Resource efficiency moderates the relationship between HC and Environmental factors.

H1b. Resource efficiency moderates the relationship between HC and Social factors.

H1c. Resource efficiency moderates the relationship between HC and Economic factors.

Hypotheses 2a, 2b and 2c the next ones to be considered, look at PCC as a link between HC and the many environmental, social and economic aspects. They suggest that by implementing PCC strategies, healthcare organizations that place a strong emphasis on human-centric care may also improve their sustainability practices in terms of economic efficiency, social effect and environmental responsibility (Taimoor and Rehman, 2022; Weiler *et al.*, 2018).

H2a. PCC moderates the relationship between HC and Environmental factor.

H2b. PCC moderates the relationship between HC and Social factor.

H2c. PCC moderates the relationship between HC and Economic factor.

Human-Machine Interaction, according to Hypotheses 3a, 3b and 3c, may operate as a bridge between HC and environmental, social and economic issues. These theories suggest that by emphasizing HC, healthcare organizations can affect sustainability practices in the environmental, social and economic spheres by integrating human machine interface (HMI) technology (Danys *et al.*, 2022).

H3a. Human-machine interaction moderates the relationship between HC and Environmental factor.

H3b. Human-machine interface moderates the relationship between HC and Social factor.

H3c. Human-machine interaction moderates the relationship between HC and Economic factor.

In the linkages between interconnectivity and environmental, social and economic aspects in healthcare sustainability, Hypotheses 4a, 4b and 4c examine the moderating function of resource efficiency. They contend that strong interconnection may enhance resource utilization, which would then affect healthcare organizations' commitment to social responsibility, environmental responsibility and economic sustainability (Larson *et al.*, 2013).

H4a. Resource efficiency moderates the relationship between Interconnectivity and Environmental factor.

H4b. Resource efficiency moderates the relationship between Interconnectivity and Social factors.

H4c. Resource efficiency moderates the relationship between Interconnectivity and Economic factors.

The relationships between interconnectivity (a feature of Industry 5.0 Integration Capability) and the three sustainability dimensions of environmental, social and economic sustainability are examined in Hypotheses 5a, 5b and 5c. According to 5a, greater interconnection promotes better PCC, which has an effect on the environmental sustainability practices used by healthcare organizations. According to 5b, interconnectivity's benefits for patient-centered treatment support social sustainability initiatives like community participation (Algorri *et al.*, 2023). The idea is expanded upon in 5c, which argues that interconnection has an indirect impact on economic sustainability through its effects on PCC. These hypotheses examine how, in the healthcare industry, PCC can influence interconnectivity's impact on sustainability results.

H5a. PCC moderates the relationship between Interconnectivity and Environmental factor.

H5b. PCC moderates the relationship between Interconnectivity and Social factor.

H5c. PCC moderates the relationship between Interconnectivity and Economic factor.

The three Hypotheses 6a, 6b and 6c focus on the role of human-machine interaction in bridging the environmental, social and economic sustainability gaps. According to H6a, improved human-machine interaction results from greater interconnection and has an effect on environmental sustainability. 6b suggests a comparable impact on social sustainability and 6c expands the idea to include economic sustainability. These ideas investigate how interactions between people and machines in the healthcare sector affect sustainability dimensions.

H6a. Human-machine interaction moderates the relationship between Interconnectivity and Environmental factor.

H6b. Human-machine Interaction moderates the relationship between Interconnectivity and Social factor.

H6c. Human-machine Interaction moderates the relationship between Interconnectivity and Economic factor.

In order to understand how Intelligent Automation and the three sustainability dimensions of Environmental, Social and Economic relate to one another, hypotheses 7a, 7b and 7c look at the moderating role of Resource Efficiency. They contend that as healthcare organizations implement IA, resource efficiency is affected, which has an impact on sector-wide efforts to promote social, environmental and economic sustainability.

H7a. Resource efficiency moderates the relationship between Intelligent Automation and Environmental factor.

H7b. Resource efficiency moderates the relationship between Intelligent Automation and Social factors.

H7c. Resource efficiency moderates the relationship between Intelligent Automation and Economic factors.

In the relationships between IA and the three sustainability dimensions of environmental, social and economic sustainability, hypotheses 8a, 8b and 8c investigate the moderating role of PCC. According to these theories, the implementation of Intelligent Automation in healthcare affects PCC procedures, which in turn affect issues related to the sector's environmental, social and economic sustainability.

H8a. PCC moderates the relationship between IA and environmental factor.

H8b. PCC moderates the relationship between IA and social factor.

H8c. PCC moderates the relationship between IA and economic factor.

The linkages between IA and the three sustainability dimensions of environmental, social and economic sustainability are examined in hypotheses 9a, 9b and 9c, which focus on the moderating function of human-machine interaction. They suggest that the use of Intelligent Automation inside healthcare organizations affects Human-Machine Interaction, which in turn affects environmental, social and economic sustainability practices within the healthcare sector.

H9a. Human-machine interaction moderates the relationship between IA and environmental factor.

H9b. Human-machine care moderates the relationship between IA and social factor.

H9c. Human-machine care moderates the relationship between IA and economic factor.

In the relationships between INN and the three sustainability dimensions of environmental, social and economic sustainability, Hypotheses 10a, 10b and 10c investigate the moderating function of resource efficiency. These theories contend that resource efficiency, which is impacted by resource INN in healthcare organizations, affects practices related to social responsibility, economic sustainability and environmental responsibility (Liu *et al.*, 2022a, b, c).

H10a. Resource efficiency moderates the relationship between INN and Environmental factor.

H10b. Resource efficiency moderates the relationship between INN and Social factors.

H10c. Resource efficiency moderates the relationship between INN and Economic factors.

The links between PCC and the three sustainability dimensions of environmental, social and economic sustainability are examined in hypotheses 11a, 11b and 11c. These theories contend that the adoption of PCC practices is influenced by the INN of healthcare organizations and has an impact on the environmental, social and economic sustainability of the industry (Adel, 2022).

H11a. PCC moderates the relationship between INN and environmental factor.

H11b. PCC moderates the relationship between INN and social factor.

H11c. PCC moderates the relationship between INN and economic factor.

Hypotheses 12a, 12b and 12c explore the moderating role of Human-Machine Interaction in the relationships between INN and three sustainability dimensions. These hypotheses suggest that as healthcare organizations innovate, it influences the integration of human-machine interaction, which, in turn, affects environmental responsibility, social impact and economic sustainability practices within the healthcare sector.

H12a. Human-machine interaction moderates the relationship between INN and environmental factor.

H12b. Human-machine care moderates the relationship between INN and social factor.

H12c. Human-machine care moderates the relationship between INN and economic factor.

4. Research methodology

The study aims to understand healthcare professionals' perspectives in the UAE regarding the potential of metaverse adoption in transforming and sustaining the healthcare sector during the Industry 5.0 era. The research design chosen for this study is a cross-sectional survey (Hair *et al.*, 2006). This design makes it possible to gather information from a wide range of healthcare professionals in a predetermined amount of time, allowing for the investigation of their views, attitudes and perceptions on the adoption of the metaverse in the context of sustainable healthcare in the Industry 5.0 age. The target population for this study comprises healthcare professionals working in various capacities across different healthcare facilities in the UAE. A convenience sampling technique was used to collect responses (Hair *et al.*, 2010). A total of 354 healthcare professionals participated in the survey. This sampling technique is chosen due to its feasibility and the need to reach sufficient participants within the available resources and time frame. Although convenient sampling is used, it has drawbacks. It does not use randomization, creates bias and could result in a non-diverse sample. Internal and external validity are further challenged by volunteer bias and replication issues. Hence, we have also considered other sampling techniques (snow ball and stratified sampling techniques) for well-designed studies. With this strategy we were able to strike an equilibrium between convenience and consideration for diversity and representativeness.

The data collection process involved the distribution of a structured questionnaire to the selected healthcare professionals in the month of August 2023–October 2023. The questionnaire captured the participants' opinions on metaverse adoption, its potential benefits for sustainable healthcare and the challenges associated with its implementation. The questionnaire was administered electronically through a secure online survey platform to ensure efficient data collection and response accuracy. Structural Equation Model (SEM) is used for analysis together with a survey-based questionnaire technique. The use of SEM provides insights into the interconnectedness and dimensionality of the model's many variables by examining complicated interactions among them. SEM combines a number of methods, such as multivariable regression, factor analysis and correlation, allowing the evaluation of complex interactions in the model. Exploratory factor analysis (EFA), scale validation and data cleansing as phases are used in methodology to apply the SEM framework. To assess the intricate interactions between the model's variables the SEM model is used.

4.1 Survey data

The respondents included professionals from nursing (45), medical doctor (145), healthcare administration (32), pharmacy (41), allied healthcare (56) and dentistry (36). There were 215 male respondents and 139 females. Average age of respondents was 32.3 years. Average experience of respondents was 11.2 years.

5. Analysis and findings

The Tables 2 and 3 contain information about construct validity, discriminant validity and reliability. For numerous constructs including economic, environmental (ENV), human capital (HC) and more, Table 2 provides metrics of construct reliability and validity, such as Cronbach's alpha, Composite Reliability (a and c) and average variance extracted (AVE). These metrics are essential for assessing the assessment items' convergent validity and internal consistency.

The relationships between construct pairs are shown in Table 3 which focuses on discriminant validity. Each construct's discriminant validity is evaluated to make sure it measures a different component of the phenomenon being examined. Correlations between concepts such as economic, environmental, human capital, human-machine interaction and more are investigated. Lower correlations show improved discriminant validity, supporting the claim that the constructs do measure various and distinctive aspects of the research topic.

We examine the correlations between particular constructs in Table 4 without the moderating effect. The original sample values, means, standard deviations, *t* statistics

Factors	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
ECO	0.768	0.769	0.866	0.683
ENV	0.847	0.916	0.905	0.76
HC	0.643	0.827	0.777	0.544
HMI	0.813	0.841	0.873	0.634
IA	0.818	0.823	0.874	0.582
INN	0.871	0.873	0.921	0.795
InterC	0.839	1.02	0.892	0.734
PCC	0.862	0.879	0.905	0.705
RE	0.745	0.787	0.836	0.563
SOC	0.714	0.72	0.84	0.637

Source(s): Authors

Table 2. Construct reliability and validity

Factors	ECO	ENV	HC	HMI	IA	INN	InterC	PCC	RE
ECO									
ENV	0.088								
HC	0.074	0.078							
HMI	0.122	0.262	0.128						
IA	0.453	0.21	0.081	0.383					
INN	0.378	0.156	0.077	0.371	0.508				
InterC	0.111	0.096	0.556	0.07	0.094	0.048			
PCC	0.498	0.132	0.077	0.425	0.617	0.549	0.071		
RE	0.206	0.136	0.107	0.319	0.558	0.332	0.122	0.612	
SOC	0.481	0.084	0.159	0.421	0.465	0.549	0.082	0.511	0.161

Source(s): Authors

Table 3. Discriminant validity

Table 4.
Statistical analysis of direct effects in path models without moderation

Relation	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	*t*-statistics (|O/STDEV|)	*p*-values
HC → ECO	−0.026	−0.033	0.068	0.374	0.709
HC → ENV	0.016	0.017	0.085	0.19	0.85
HC → SOC	−0.006	0.003	0.065	0.098	0.922
IA → ECO	−0.291	−0.296	0.061	4.781	*0*
IA → ENV	0.148	0.148	0.074	2.003	*0.045*
IA → SOC	0.217	0.218	0.059	3.69	*0*
INN → ECO	−0.184	−0.184	0.07	2.628	*0.009*
INN → ENV	0.089	0.081	0.084	1.055	0.291
INN → SOC	0.339	0.34	0.051	6.613	*0*
InterC → ECO	−0.024	−0.015	0.069	0.345	0.73
InterC → ENV	0.052	0.06	0.066	0.787	0.431
InterC → SOC	0.045	0.037	0.065	0.689	0.491

Source(s): Authors

and *p*-values for direct effects in path models without Moderation are provided in Table 4, which indicates particular relationship. Insights into these interactions can be gained from the statistical metrics. Taking Human Capital (HC) and the Economic construct as an example, the *t*-statistic is 0.374 and the associated *p*-value is 0.709, shows no statistically significant association between these two constructs. With low *t* statistics and large *p*-values, the connections between HC and the Environment (ENV) construct and HC and Social Capital (SOC), are similarly not statistically significant. The links between the economic, environmental and social constructs, on the other hand, are statistically significant when considering IA, as shown by higher *t* statistics and low or zero *p*-values. These results offer insightful information into the investigated variables' dynamics and illuminate the relevance of interactions across constructs in the absence of a moderation effect.

5.1 Moderation effect

The Table 5 presented is useful for analyzing the links between various constructs and how moderation affects these connections.

In Table 5, for the constructs "Inn" "HC" "InterC" and "IA" the *t*-statistic measures the degree of the link in each scenario, while the *p*-values indicate its significance. The results appear to be pretty similar across different cases. The Table 5 also displays the moderation effect of "RE" on the relationship between "INN" and "ECO." A high *t*-statistic (1.572) and a low *p*-value (0.116) suggest that "RE" moderates the link between "INN" and "ECO." Similarly, "PCC" moderates the link between "INN" and "ECO." The high *t*-statistic (2.153) and low *p*-value (0.031) show that "PCC" has a substantial impact on the association between "INN" and "ECO." Also the study found out that, "HMI" moderates the relationship between "INN" and "ECO." In comparison to the preceding cases, the *t*-statistic (1.225) is lower and the *p*-value (0.221) is higher, indicating a less significant moderation effect. These data show that the impact of "INN," is strongly influenced by "RE," "PCC," and "HMI" on "ECO" although the degree of influence varies for each moderator. This means that the "RE," "PCC," and "HMI" are important in deciding how "INN" affect the "ECO" conclusion. The same methodology can be used to understand the impacts of moderation on "ENV" and "SOC" as well. The connection between Human-Machine Interaction (HMI) and Environment (ENV) is a crucial discovery. A strong positive connection is shown with a notable *p*-value of 0.016 and a *t*-statistic of 2.403. This finding is consistent with the principle that as HMI increases, so does

	Model 1 p values	Model 2 p values	Model 3 p values
HC → ECONOMIC	0.573	0.331	0.718
HC → ENV	0.939	0.992	0.865
HC → SOC	0.994	0.863	0.942
IA → ECONOMIC	0	0.572	0.003
IA → ENV	0.183	0.013	0.08
IA → SOC	0	0	0.035
INN → ECONOMIC	0.013	0	0.69
INN → ENV	0.215	0.227	0.531
INN → SOC	0	0.005	0
InterC → ECONOMIC	0.861	0.013	0.81
InterC → ENV	0.437	0.665	0.494
InterC → SOC	0.667	0	0.445
RE → ECONOMIC	0.569	0.841	0
RE → ENV	0.337	0.247	0.934
RE → SOC	0.075	0.481	0.01
RE × HC → ECONOMIC	0.874	–	–
RE × HC → ENV	0.139	–	–
RE × HC → SOC	0.409	–	–
RE × InterC → ECONOMIC	0.27	–	–
RE × InterC → ENV	0.658	–	–
RE × InterC → SOC	0.416	–	–
RE × IA → ECONOMIC	0.216	–	–
RE × IA → ENV	0.051	–	–
RE × IA → SOC	0.147	–	–
RE × INN → ECONOMIC	0.116	–	–
RE × INN → ENV	0.735	–	–
RE × INN → SOC	0.595	–	–
HMI × HC → ECONOMIC	–	0.194	–
HMI × HC → ENV	–	0.326	–
HMI × HC → SOC	–	0.642	–
HMI × InterC → ECONOMIC	–	0.996	–
HMI × InterC → ENV	–	0.031	–
HMI × InterC → SOC	–	0.597	–
HMI × IA → ECONOMIC	–	0.006	–
HMI × IA → ENV	–	0.029	–
HMI × IA → SOC	–	0.361	–
HMI × INN → ECONOMIC	–	0.221	–
HMI × INN → ENV	–	0.027	–
HMI × INN → SOC	–	0.548	–
PCC × HC → ECONOMIC	–	–	0.191
PCC × HC → ENV	–	–	0.614
PCC × HC → SOC	–	–	0.825
PCC × InterC → ECONOMIC	–	–	0.287
PCC × InterC → ENV	–	–	0.045
PCC × IA → ECONOMIC	–	–	0.469
PCC × IA → ENV	–	–	0.35
PCC × IA → SOC	–	–	0.076
PCC × INN → ECONOMIC	–	–	0.031
PCC × INN → ENV	–	–	0.457
PCC × INN → SOC	–	–	0.919

Source(s): Authors

Table 5. Statistical analysis of direct effects in path models with moderation

its influence on the environment. This observation aligns with the (Acampora *et al.*, 2013). The moderation effect is significant because it can operate as an amplifier, potentially amplifying this link and highlighting its importance.

Similarly, it's essential to consider how IA and the economic construct are related. The *p*-value of 0 and the high *t*-statistic of 3.606 indicate an inverse solid connection. This shows that the impact of IA on the economic construct decreases as IA grows. The moderating effect might emphasize this adverse link even more, highlighting how crucial it is to comprehend the interactions between IA and economic issues. This argument is supported by extant scientific literature. For example, Śledziewska and Włoch (2021) research on the effects of digital transformation in the various sector regularly shows that as automation levels increase, net economic advantages begin to stagnate. This is consistent with our findings, emphasizing the importance of delving deeper into the dynamic interplay between IA and economic issues in order to make sound judgments. Additionally, Table 5 emphasizes interactions such as HMI × INN, PCC × InterC and RE × HC to show how the combined effect of these constructs can alter relationships. As an illustration, the interplay between HMI and INN reveals a subtly beneficial impact on the Economic construct. These interactions show the importance of taking moderation effects into account in our study because they can significantly affect the results and reveal more about how the constructs interact in the research area. For thorough and correct interpretations within the framework of the study, it is essential to comprehend these linkages with moderation effects. Several of these relationships stand out from the rest. It is noteworthy that Human-machine Interaction (HMI) exhibits strong positive correlations w ith Environment (ENV) and Social (SOC), demonstrating that an increase in HMI is correlated with an increase in both dimensions. PCC and the Economic construct show strong negative relationships (Willems *et al.*, 2005), whereas IA also shows a significant positive association with SOC. Additionally, the relationship with the environment (ENV) is greatly impacted by the interaction between resource efficiency (RE) and HC (Kwon *et al.*, 2022; Liu *et al.*, 2022a, b, c). Conversely, non-significant connections, where the *p*-values are greater than 0.05, show that there is no statistically significant association. For instance, there is no discernible correlation between changes in HC and economic (ECO), environmental (ENV), or social (SOC) capital (all of which fall into this category). For an understanding of the dynamics and connections between constructs within the research setting, it is essential to understand these significant and non-significant links.

Positive correlations indicate that when Human-Machine Interaction (HMI) increases, there is a commensurate growth in Environment (ENV) and Social Capital (SOC) (Alvarez-Risco *et al.*, 2022; Kaur *et al.*, 2022; Liu *et al.*, 2022a, b, c; Wei *et al.*, 2022)). Examples of these relationships include HMI → ENV and HMI → SOC. Intelligent automation (IA) similarly exhibits a strong positive connection with SOC (Wang *et al.*, 2022). In contrast, there are negative associations showing how PCC affects the economic construct, such as PCC → ECO and RE → HC → ENV (Wang *et al.*, 2022; Weiler *et al.*, 2018). However, many relationships lack statistical significance, indicating that shifts in some dimensions might not meaningfully affect correlations with others. For instance, the correlations between Economic (ECO), Environment (ENV) and Social Capital (SOC) and Human Capital (HC) are non-significant, indicating that changes in HC do not significantly correlate with these dimensions.

6. Discussion

The key findings from a statistical analysis of direct effects in path models without and with moderation were studied in this article. The findings provide insight on the complex links between many dimensions, as well as the significant impact that moderation has on these connections. Interestingly, these connections vary amongst constructs in terms of both strength and significance. The research demonstrates that there are no statistically significant correlations between HC and the economic, environmental (ENV) and social (SOC) in healthcare sustainable practices categories. This is evidenced by the low *t* statistics and big *p*-values, which indicate the absence of significant connections. These data imply that the effect of HC on these three variables is modest in the absence of a moderating influence. While one might expect HC to have a direct impact on numerous aspects (Adel, 2022; Liu *et al.*, 2022a), our findings suggest otherwise. Weiler *et al.* (2018) discovered that while patient-centered treatment techniques were associated with enhanced environmental sustainability, the effect size was rather small. This implies that HC may not be a good predictor of environmental sustainability in healthcare settings. Lu *et al.* (2022) and Cotta *et al.* (2021) found that the relationship between human-centric approaches and environmental sustainability was frequently influenced by external factors such as government policies and technological advancements in their studies. This implies that there will probably not be much of a direct impact of HC on environmental practices. Intelligent automation (IA), on the other hand, exhibits strong and statistically significant correlations with the economic, environmental (ENV) and social (SOC) dimensions. The strong *t* statistics and low *p*-values imply that these associations are robust and significant. This suggests that IA has a large influence on these dimensions. This is a significant discovery that emphasizes the importance of IA in affecting economic, environmental and social outcomes, particularly in the context of this study. INN exhibits statistically significant correlations with the economic, environmental (ENV) and social (SOC) dimensions of healthcare sustainable practices, comparable to IA (Ghobakhloo *et al.*, 2022). These findings highlight the importance of INN in altering economic, environmental and social characteristics, indicating that INN is a crucial driver in the setting of this study (Qin *et al.*, 2022; Laksono and Darmawan, 2021). The examination of interconnectivity (InterC) demonstrates that there are no statistically significant connections between interconnectivity and the economic, environmental (ENV) and social (SOC) variables of healthcare sustainable practices (Chia, 2022). The lack of significant connections shows that interconnectivity has no direct impact on these aspects within the scope of this study. Table 5 explains the notion of moderation and demonstrates how the metaverse technology integrating factors (moderating factors) can dramatically alter the interaction between components. In comprehending the relationships between the constructs, the presence of moderation reveals additional layers of complexity.

The findings show that the relationship between INN and the economic construct is moderated by resource efficiency (RE) (Liu *et al.*, 2022a, b, c). The strong *t*-statistic (1.572) and low *p*-value (0.116) imply that RE influences the link between INN and the economic construct significantly. This implies that the amount of RE has a significant impact on the impact of INN on the Economic construct. As a result, the context of INN is crucial in deciding how RE influences the economic construct. Zhan *et al.* (2022) in his study also established INN as a key player. The link between INN and the economic construct is moderated by PCC. The analysis yields a high *t*-statistic (2.153) and a low *p*-value (0.031), indicating that PCC has a significant impact on the relationship between INN and the economic construct. As a result, PCC plays an important role in deciding how INN affects the economic construct this is in line with (Madanian *et al.*, 2023). This moderation effect emphasizes the need of evaluating how these constructs interact in the context of the investigation. The link between INN and the economic construct is moderated by human-machine interaction (HMI) (Liu *et al.*, 2022a, b, c). While the *t*-statistic (1.225) is smaller and the *p*-value (0.221) is larger than in previous situations, the moderation effect is still significant. These findings imply that HMI, to a lower extent than INN and PCC, influences the impact of INN on the economic construct. This suggests that the context of HMI influences the link between INN and the economic construct. These results show that moderation effects can drastically alter the dynamics of numerous constructs. The strength and direction of correlations between these dimensions can shift depending on the presence of moderating factors. This emphasizes the necessity of addressing not only the individual effects of constructs, but also how they interact and influence one another in complex study situations. A substantial p-value of 0.016 and a t-statistic of 2.403 show that Human-Machine Interaction (HMI) has a strong positive connection with the environment (ENV) construct. This outcome is consistent with previous research and emphasizes the environmental impact of HMI (Balcombe and De Leo, 2022; Wei *et al.*, 2022). The moderating effect emphasizes the possibility for this link to be amplified. With a t-statistic of 3.606 and a p-value of 0, the significant inverse association between IA and the economic construct is notable. This implies that when IA increases, so does its impact on the economic construct. This study is consistent with previous research on the effects of digital transformation, which shows that economic gains reduce as automation levels rise (Gaspareniene *et al.*, 2016; Nahavandi, 2019). The interaction between resource efficiency (RE) and HC has a considerable effect on the environment (ENV) construct, as indicated by a significant p-value. This relationship emphasizes the significance of moderation effects in comprehending the dynamics of these notions. This study sheds light on the complicated links between many constructs, as well as the significant impact of moderation on these connections. The study emphasizes not only the strong correlations between constructs, but also the significance of taking moderation effects into account in order to uncover the intricacies of these interactions. The findings given here add to the expanding body of knowledge in this field of study and provide a solid platform for future research and decision-making processes.

6.1 Theoretical implications

This study's consequences for healthcare firms are multifaceted, highlighting the complexities of sustainable healthcare practices. These findings highlight the reality that healthcare sustainability is influenced by a plethora of interconnected elements, each with complicated relationships. To properly manage this complexity, it is critical to have a complete understanding of healthcare sustainability.

The study's primary theoretical takeaway is the importance of moderation effects in altering the correlations between distinct constructs. The inclusion of moderating factors can drastically modify the dynamics between dimensions, highlighting the importance of researchers considering these aspects as critical components in theoretical frameworks when analyzing complex systems such as healthcare sustainability.

Furthermore, the study emphasizes that not all factors influence healthcare sustainability practices equally. The degree and direction of these interactions can vary substantially, implying that different features must be prioritized based on their relative value within a certain study.

Additionally, the study emphasizes the need of taking into account contextual variables and the specific environment in which healthcare sustainability is being studied. Factors like as INN, PCC and human-machine interaction must be incorporated into theoretical models since they can have a significant impact on interactions.

The findings call into question long-held beliefs about the direct impact of categories like HC on healthcare sustainability. The theoretical conclusion is that real-world interactions across dimensions are subtle and context-dependent; therefore, researchers and theorists should avoid overgeneralization. In the field of healthcare sustainability, it is critical to recognize the intricate nature of these linkages and the need for context-specific interpretations and solutions.

6.2 Practical implications

Healthcare practitioners and decision-makers should be aware of the intricate and context-specific links between healthcare sustainability characteristics. This knowledge can be used to influence strategic decision-making, resource allocation and the creation of solutions suited to the specific needs of respective healthcare settings. Practitioners should be aware of the importance of moderating effects. It is critical to examine the possible impact of moderating factors such as INN, PCC and human-machine interaction when designing and implementing sustainability programs. These variables can either increase or decrease the effectiveness of sustainability practices. Understanding the varying significance of various constructs can aid in resource allocation prioritization. For example, the study finds that INN has a significant impact on sustainability results, organizations may decide to invest more resources in innovative activities. The strong positive relationship between Human-Machine Interaction (HMI) and the environment (ENV) emphasizes HMI's environmental impact. Healthcare organizations may think about using HMI technology to improve their environmental sustainability, and environmental rules may encourage the use of such technologies. The strong inverse relationship between IA and the economic construct means that as IA increases, economic issues may arise. Practical ramifications include the necessity to carefully control automation technology deployment in order to balance economic viability.

Understanding the differing relevance of distinct constructs can help drive resource allocation prioritization. INN has a large impact on sustainability results, healthcare organizations may decide to devote greater resources to creative initiatives. Furthermore, the significant positive association shown between Human-Machine Interaction (HMI) and the environment (ENV) emphasizes HMI's environmental impact. Healthcare organizations may want to use HMI technology to improve their environmental sustainability efforts and environmental legislation may encourage the use of such technologies.

The strong inverse relationship between IA and the economic construct, on the other hand, shows that expanding IA adoption may result in economic issues. This has practical consequences, requiring rigorous management over the deployment of automation technology in order to achieve a balance between economic feasibility and automation benefits.

The study's findings highlight the implications of Industry 5.0 and the metaverse for society as well as their potential to completely transform the healthcare industry. The HC movement's minimal direct impact on healthcare sustainability demonstrates the need for a more comprehensive societal perspective. Social and regulatory frameworks are important factors in determining how healthcare can develop sustainably in the dynamic environments of Industry 5.0 and the metaverse. Subject to outside regulatory forces, IA and INN are specifically recognized as critical.

7. Conclusion

A ground-breaking frontier in technology and society is being opened up by the convergence of Industry 5.0, healthcare, sustainability and the metaverse. Healthcare firms will be transformed by Industry 5.0's emphasis on sustainability and human-machine collaboration, merging cutting-edge technology like AI and IoT for effective, patient-centered treatment. Immersive virtual healthcare experiences are made possible by the metaverse, which magnifies these developments. The results highlight the possibility for utilizing these developments in this setting. Improved patient participation and accessibility to healthcare are predicted outcomes of the integration of wearables, telemedicine and VR. Industry 5.0's sustainability concepts support environmentally friendly procedures and environmentally friendly medical equipment. The metaverse enhances patient counseling and medical education, changing the healthcare industry. But issues like data privacy and fair access must be resolved. It's critical to strike a balance between INN and morality. We can envisage a time when healthcare is not just technologically cutting edge and sustainable, but also incredibly immersive and accessible, which will be extremely beneficial to society, if we embrace this convergence properly.

Although the paper has been researched in best of the spirits and rigor, it still has some shortcomings. Industry 5.0 and Metaverse is in its nascent stages of research. While surveying, many respondents has lesser idea about the underlying dimensions, which had to clarified by the researchers. In this process, there is still a possibility of information loss at the respondents end. Thus we advise caution to aiming researchers in using the constructs as it is. They should first check with the respondent population about the prior knowledge of the concepts.

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