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The Metaverse - Intellectual Capital Nexus: Unlocking Sustainable Entrepreneurial Innovation

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Abstract

The rapid advancement of immersive digital technologies has positioned the metaverse as a strategic enabler of industrial transformation, offering new opportunities for knowledge creation, operational excellence, and sustainable innovation. Despite increasing scholarly interest, limited empirical evidence exists regarding the mechanisms through which metaverse technologies promote sustainable entrepreneurial innovation, particularly within industrial organisations in developing economies. This study investigates the direct effects of metaverse technologies on intellectual capital (IC) and sustainable entrepreneurial innovation (SEI), while examining the mediating role of IC in this relationship. Drawing upon the Unified Theory of Acceptance and Use of Technology, the Resource-Based View, Dynamic Capabilities Theory, and IC Theory, a conceptual model was developed and empirically tested. Data were collected from 339 managers, assistant managers, information technology professionals, and employees working in Iraqi industrial organisations using a structured questionnaire. The proposed hypotheses were analysed using Partial Least Squares Structural Equation Modelling. The findings reveal that metaverse technologies significantly enhance IC and directly foster SEI. IC also exerts a strong positive influence on SEI and partially mediates the relationship between metaverse technologies and innovation outcomes, demonstrating that the strategic value of immersive technologies is realised through the development of human, structural, and relational capital. The study contributes to the emerging metaverse literature by integrating complementary theoretical perspectives into a unified framework and provides practical guidance for industrial organisations seeking to leverage immersive technologies to strengthen IC, accelerate SEI, and enhance long-term competitive advantage.

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1. Introduction

The emergence of the metaverse represents one of the most profound technological transformations of the Fourth Industrial Revolution, fundamentally reshaping how organisations create knowledge, collaborate, innovate, and generate sustainable value. Unlike previous waves of digital transformation that primarily focused on automation and connectivity, the metaverse integrates virtual reality (VR), augmented reality (AR), extended reality (XR), artificial intelligence (AI), blockchain, cloud computing, digital twins, and the Internet of Things (IoT) into immersive digital ecosystems where physical and virtual environments coexist and interact seamlessly (Aiolfi & Luceri, 2024; Davies et al., 2024; Rafique & Qadir, 2024). Global industries are increasingly recognising the metaverse as more than a technological novelty; rather, it is becoming a strategic infrastructure capable of transforming manufacturing systems, product development, employee training, supply chain management, and collaborative innovation (Contreras et al., 2022; Wen et al., 2025). As industrial organisations face unprecedented pressures arising from environmental regulations, digital disruption, resource scarcity, and intensified global competition, the ability to exploit immersive technologies has become a critical determinant of sustainable competitiveness.

The industrial sector is currently undergoing a rapid transition from traditional manufacturing towards smart, interconnected, and sustainable production systems, where digital technologies increasingly determine organisational resilience and long-term performance. Industry 4.0 technologies have already demonstrated considerable potential for improving operational efficiency, reducing waste, and supporting environmentally sustainable manufacturing practices. However, recent technological developments suggest that the metaverse represents the next evolutionary stage of industrial digitalisation by enabling organisations to simulate entire production environments, optimise operational processes, conduct virtual experimentation, and facilitate real-time collaboration among geographically dispersed stakeholders (Latino et al., 2024; Lyu & Fridenfalk, 2024; Meng et al., 2025). Through immersive virtual environments, organisations can evaluate production alternatives, minimise material waste, optimise energy consumption, and accelerate product innovation before committing physical resources, thereby reducing costs while simultaneously supporting environmental sustainability (Yaseen et al., 2025; Yoşumaz, 2024). Consequently, metaverse technologies are increasingly viewed as strategic enablers of sustainable industrial transformation rather than merely advanced digital communication platforms.

Parallel to the rapid advancement of immersive technologies, intellectual capital (IC) has become one of the most valuable strategic resources enabling organisations to transform technological investments into sustainable competitive advantage. Contemporary organisations increasingly recognise that long-term competitiveness depends less on physical assets and more on their ability to generate, integrate, and exploit knowledge embedded within employees, organisational systems, and stakeholder relationships (Ahmed et al., 2023; Jordao & Novas, 2022; Paoloni et al., 2022). IC, comprising human capital, structural capital, and relational capital, provides the organisational capabilities required to absorb emerging technologies, institutionalise organisational knowledge, facilitate collaborative learning, and accelerate innovation (Abdelfattah et al., 2024; Truong & Nguyen, 2024). The integration of immersive digital technologies with IC therefore represents an increasingly important research domain, particularly as organisations seek to translate digital transformation initiatives into sustainable organisational outcomes.

Simultaneously, organisations are experiencing growing pressure to pursue sustainable entrepreneurial innovation (SEI), which extends beyond conventional innovation by integrating economic performance with environmental stewardship and social responsibility (Baber, 2023; Diepolder et al., 2024). SEI encompasses the development of environmentally responsible products, resource-efficient production systems, circular business models, and socially responsible entrepreneurial initiatives that generate long-term value for multiple stakeholders (Freudenreich et al., 2019; Osei Opoku et al., 2024). As industrial organisations increasingly adopt digital technologies to achieve sustainability objectives, understanding the organisational mechanisms through which metaverse technologies stimulate SEI has become a strategic priority for both researchers and practitioners.

Despite the growing scholarly interest in the metaverse, existing research remains fragmented in several important respects. First, most previous studies have concentrated on consumer behaviour, education, tourism, healthcare, retail, and entertainment, while empirical investigations within industrial and manufacturing organisations remain comparatively limited (Contreras et al., 2022; Lim et al., 2024; Moustapha et al., 2024). Second, although numerous studies acknowledge the technological capabilities of the metaverse, relatively little empirical evidence explains how these technologies generate strategic organisational outcomes, particularly SEI. Most existing research focuses on technology adoption or user acceptance rather than examining the organisational processes that transform immersive technologies into innovation capabilities (Aiolfi & Luceri, 2024; Markopoulos et al., 2022). Third, IC and metaverse technologies have largely evolved as independent streams of research. While IC has been extensively examined as a driver of innovation and competitive advantage (Amaya et al., 2022; Secundo et al., 2020), few empirical studies have investigated whether IC functions as the organisational mechanism through which metaverse technologies influence SEI.

These limitations reveal an important theoretical and empirical gap. Current literature provides only limited understanding of the interrelationships among metaverse technologies, IC, and SEI, particularly within industrial organisations operating in developing economies. Moreover, although the Unified Theory of Acceptance and Use of Technology (UTAUT) effectively explains technology adoption behaviour (Venkatesh et al., 2012), it provides limited insight into how actual technology use contributes to broader organisational capabilities and innovation outcomes. Similarly, the Resource-Based View (RBV) and Dynamic Capabilities Theory emphasise the strategic importance of valuable organisational resources and knowledge reconfiguration (Jordao & Novas, 2022; Pitelis et al., 2023), yet empirical evidence integrating these perspectives within the metaverse context remains scarce. Consequently, there is a clear need for an integrated theoretical framework capable of explaining how immersive digital technologies create sustainable entrepreneurial value through organisational knowledge resources.

This research addresses these shortcomings by developing and empirically testing an integrated model that combines UTAUT, Resource-Based View, Dynamic Capabilities Theory, and IC Theory to explain how the actual use of metaverse technologies contributes to SEI. Specifically, the study proposes that metaverse technologies enhance IC by strengthening employees' competencies, organisational knowledge infrastructures, and collaborative stakeholder networks, which subsequently facilitate SEI. In doing so, the study positions IC as the critical organisational mechanism through which digital transformation is translated into sustainable innovation performance.

The empirical investigation is conducted within the Iraqi industrial sector, an important yet underexplored context characterised by increasing digital transformation initiatives, growing sustainability challenges, and substantial pressure to enhance industrial competitiveness. Industrial organisations in Iraq are progressively investing in advanced digital technologies to modernise manufacturing operations, improve productivity, and achieve sustainable development objectives. Nevertheless, empirical evidence regarding the organisational value of metaverse technologies within this context remains extremely limited. By focusing on Iraqi industrial organisations, the study contributes valuable evidence from a developing economy, thereby extending the external validity of existing theories beyond the predominantly developed-country settings that dominate current research.

Accordingly, the primary objective of this study is to examine the direct effect of metaverse technologies on IC and SEI, to investigate the influence of IC on SEI, and to determine whether IC mediates the relationship between metaverse technologies and SEI. The central argument advanced in this paper is that metaverse technologies alone do not generate SEI; rather, their strategic value is realised through the development and mobilisation of IC, which transforms immersive digital capabilities into sustainable organisational innovation and long-term competitive advantage. To achieve this objective, the remainder of the paper is organised as follows. Section 2 reviews the relevant literature and develops the research hypotheses. Section 3 describes the research methodology and data analysis procedures. Section 4 presents the empirical findings, followed by the discussion in

Section 5. Finally, Sections 6 and 7 conclude the paper by outlining its theoretical contributions, practical implications, limitations, and directions for future research.

2. Theoretical Background and Hypothesis Development

2.1 Sustainable Entrepreneurial Innovation

Sustainable entrepreneurial innovation (SEI) has emerged as a strategic and dynamic capability through which organisations generate and implement novel ideas that lead to substantial and often radical improvements in products, operational processes, and business model design (Hassan et al., 2023). Its true value lies in its exceptional ability to transform creative ideas and innovative solutions into practical applications that generate sustainable competitive value for organisations while simultaneously delivering positive environmental and social outcomes. From this perspective, entrepreneurial innovation constitutes a fundamental strategic mechanism that enables organisations to address increasingly complex sustainability-related challenges and environmental pressures (Maier et al., 2020). In this regard, international organisations such as the Organisation for Economic Co-operation and Development (OECD) define entrepreneurial innovation as the implementation of a new or significantly improved product, process, or organisational approach that stimulates economic growth, strengthens competitive advantage, and prioritises environmental sustainability (Osei Opoku et al., 2024). Consequently, entrepreneurial innovation has become a critical mechanism for enabling organisations to adapt effectively to accelerating environmental and social changes while achieving superior operational efficiency within the broader context of contemporary entrepreneurship.

Organisations that embrace a sustainable entrepreneurial orientation play a pivotal role in driving and institutionalising entrepreneurial innovation. This is reflected in their ability to develop environmentally friendly products, redesign production processes to minimise emissions and waste (Lüdeke-Freund, 2019), and establish innovative business models that successfully balance economic profitability with long-term sustainability. As global demand for responsible products and business practices continues to grow, organisations face increasing pressure to adopt entrepreneurial innovation strategies that respond proactively to stakeholder expectations and address emerging societal and environmental challenges (Freudenreich et al., 2019). Accordingly, entrepreneurship provides an ideal context for leveraging these strategic orientations to develop innovative solutions that strengthen competitive advantage while simultaneously advancing comprehensive organisational sustainability (Sarma et al., 2022).

The successful implementation of entrepreneurial innovation requires a proactive strategic vision that enables organisations to anticipate future challenges and develop solutions capable of generating multidimensional value (Harvey, 2025). Its significance extends beyond responding to immediate market demands, encompassing the transformation of industries towards more resilient and sustainable business models (David-West et al., 2019). Entrepreneurial innovation therefore represents a multidimensional ecosystem comprising several complementary forms of innovation, each serving distinct strategic and competitive objectives. These include open innovation, which facilitates dynamic knowledge exchange between an organisation and its external environment (Phonthanukitithaworn et al., 2024); environmental or green innovation, which directly seeks to minimise the environmental impacts of products and operational processes while improving resource efficiency (Abbas et al., 2024); disruptive innovation, which fundamentally reshapes traditional markets and establishes new technological and competitive paradigms that support deeper sustainability transitions (Ibidunni et al., 2021); and frugal innovation, which provides cost-effective entrepreneurial solutions by optimising the use of limited resources while addressing social and environmental priorities, particularly within emerging economies (Qin, 2024; Saleem et al., 2024; Shahid et al., 2023).

According to Terán-Yépez et al. (2020), entrepreneurial innovation, represents one of the fundamental pillars of comprehensive organisational sustainability. It operates through a set of complementary roles that address unmet needs across markets and industries by directing entrepreneurial efforts towards the development of environmentally sustainable products and services. Moreover, it enhances operational efficiency through waste reduction and more effective utilisation of organisational resources, while simultaneously redesigning organisational structures and administrative processes to align with the requirements of sustainable transformation. Entrepreneurial innovation also employs innovative marketing strategies that communicate the environmental and societal value of products, thereby increasing consumer acceptance and market adoption. The integration of these complementary functions establishes a holistic framework that enables organisations to balance environmental, social, and economic objectives effectively.

Fundamentally, entrepreneurial innovation extends far beyond serving as a mechanism for improving short-term organisational performance (Nneka Adaobi et al., 2024). Rather, it constitutes a comprehensive strategic orientation that equips organisations to respond responsibly to environmental and economic pressures while reshaping their future towards more resilient, competitive, and sustainable development pathways. Accordingly, SEI, in all its forms and applications, represents a critical driver of entrepreneurial success, long-term organisational growth, and sustainable value creation.

2.2 Metaverse Technologies

The origins of the metaverse can be traced back to the early virtual environments that emerged in the 1970s through multi-user text-based network games. The concept evolved further in 1986 with the introduction of avatars, which became the fundamental building block of users' digital representation within virtual worlds (Lyu, 2023). However, the concept gained its true prominence in 1992 when Neil Stephenson coined the term metaverse in his novel Snow Crash, describing it as a three-dimensional virtual world that transcends physical limitations (Florido-Benítez, 2024; Lim et al., 2024). This vision was subsequently realised through platforms such as Second Life, which integrated social interaction with a digital economy.

With rapid technological advancements, the metaverse has evolved into a sophisticated ecosystem supported by cloud computing, blockchain, the IoT, and AI, all of which facilitate efficient data management and the seamless operation of immersive virtual environments (Rafique & Qadir, 2024). These technologies are complemented by VR, AR, XR, and advanced smart and sensory devices that substantially enhance user immersion and interaction (Moustapha et al., 2024). Academic and industrial interest in the metaverse accelerated significantly following Meta's strategic rebranding in 2021 and its commitment to developing an interconnected virtual ecosystem that seamlessly bridges the physical and digital worlds (Aiolfi & Luceri, 2024). Contemporary literature broadly defines the metaverse as an immersive, interactive, and synchronised three-dimensional digital environment that enables users to work, shop, communicate, and collaborate while simultaneously enhancing transparency and sustainability (Aiolfi & Luceri, 2024; Davies et al., 2024; Wen et al., 2025).

From both managerial and technological perspectives, the metaverse is increasingly recognised as a comprehensive digital infrastructure capable of fundamentally transforming economic and social activities (Jauhiainen, 2024). It integrates four principal technological paradigms. The first is AR, which overlays digital content onto the physical environment in real time to support operational and marketing decision-making (Egbengwu et al., 2025; Labovitz & Hubbard, 2020; Y. Wang et al., 2024; Xi et al., 2024). The second is VR, which provides fully immersive digital environments that replicate real-world experiences and facilitate advanced interactive applications (Morone et al., 2025; Y. Wang et al., 2024). The third comprises mirror worlds, which function as digital replicas of physical environments, enabling real-time simulation, monitoring, and analysis without the financial and operational costs associated with field-based experimentation (Argota Sanchez-Vaquerizo, 2025; Yazıcı et al., 2024). The fourth is lifelogging, which focuses on digitally recording users' daily activities and behaviours to improve both organisational and individual performance (Abdulmuhsin et al., 2024; Pillay et al., 2024; Winta & Fibry Jati, 2024).

The distinctive characteristics of the metaverse stem from its secure blockchain-enabled digital infrastructure, three-dimensional spatial architecture, collaborative participation, and real-time interaction (Cheung et al., 2024; Seo et al., 2024; Wang et al., 2025; Xue et al., 2024). Additional defining attributes include persistence, interoperability across multiple platforms, and scalability capable of supporting substantial volumes of users and digital content (Boo & Suh, 2024; Fernández-Caramés & Fraga-Lamas, 2024; Radanliev et al., 2024; Y. Wang et al., 2024). Furthermore, the metaverse promotes creativity, avatar-based embodiment, technological continuity, and sustainability by facilitating a balanced integration of economic, environmental, and social dimensions (Abdulmuhsin et al., 2024; Nah et al., 2025; Pizzolante et al., 2023; Rawat & El Alami, 2023; Zhang et al., 2025).

The strategic and organisational significance of these technologies extends well beyond entertainment, positioning the metaverse as a comprehensive platform for knowledge exchange and innovation across business, manufacturing, education, and healthcare sectors (Contreras et al., 2022). At the individual level, the metaverse enables users to establish virtual enterprises, foster entrepreneurial activities, and cultivate creative thinking by experimenting within secure, low-risk environments (Lim et al., 2024; Mele et al., 2024). It also provides immersive training solutions that closely replicate real-world conditions while substantially reducing the costs associated with conventional training methods. In marketing and customer relationship management, the metaverse empowers organisations to deliver highly personalised and immersive customer experiences that strengthen customer loyalty while simultaneously enabling real-time behavioural analytics to refine strategic decision-making (Jeon & Lee, 2024; Kim & Yoo, 2024).

At the organisational level, the metaverse offers an ideal environment for knowledge sharing, collaborative learning, and prototype testing within research and development settings before full-scale implementation (Alsetoohy et al., 2024). Its strategic value is further amplified when integrated with IC. Specifically, it contributes to the development of human capital by enhancing digital competencies and professional expertise, strengthens structural capital through the establishment of advanced immersive knowledge platforms and digital repositories, and enriches relational capital by expanding collaborative networks and facilitating cross-border virtual partnerships (Abrokwah-Larbi, 2024). Collectively, these capabilities enable organisations to generate distinctive and difficult-to-imitate innovations, thereby reinforcing sustainable competitive advantage and long-term innovation performance.

2.3 Intellectual Capital

Although the term Intellectual Capital (IC) was first introduced by John Kenneth Galbraith in 1969, it did not emerge as a central theme in management thought until the 1980s, when it attracted considerable attention from both academics and practitioners (Vale et al., 2022). The development of IC research has progressed through four major stages. The first stage, during the late 1980s, focused on conceptualising the terminology and establishing a shared understanding of IC. The second stage, at the beginning of the twenty-first century, concentrated on developing measurement and reporting frameworks, thereby strengthening recognition of its contribution to organisational performance (Vargas-Atencio et al., 2024). During the third stage, scholarly attention shifted towards practical applications and managerial implications (P. P. Wang et al., 2024). More recently, the fourth stage has broadened the scope of IC to encompass organisational responses to contemporary environmental, social, and demographic challenges.

Despite extensive research, no universally accepted definition of IC has emerged owing to its multidisciplinary nature and relatively recent development. One stream of research associates IC with knowledge management and its role in generating value creation and fostering innovation (Ahmed et al., 2023; Jordao & Novas, 2022), whereas another emphasises its human, structural, and relational dimensions as strategic resources for achieving sustainable competitive advantage (Ali et al., 2024). From a disciplinary perspective, management scholars view IC as a strategic organisational resource, accounting scholars consider it an intangible asset influencing financial performance (Ovechkin et al., 2020), while economists highlight its contribution to sustainable economic development (Hariyono & Narsa, 2024).

The literature generally categorises definitions of IC into three principal perspectives. The first adopts a human-centred perspective, defining IC as the collective knowledge, expertise, experience, and innovative capabilities possessed by individuals that generate organisational value (Prusak & Kardas, 2024; Vale et al., 2022). The second focuses on intangible resources, viewing IC as a portfolio of invisible knowledge assets, including organisational processes, patents, and technological capabilities that strengthen organisational competitiveness (Bagna et al., 2024). The third, and most comprehensive, is the integrated perspective, which combines human capabilities with intangible organisational resources. This approach has been adopted by the Organisation for Economic Co-operation and Development (OECD), which defines IC as knowledge-based resources, relationships, and innovation capabilities that support sustainable business performance and long-term economic growth (Achuo et al., 2024).

IC represents a vital strategic resource that enables organisations to respond effectively to dynamic environmental challenges, leverage accumulated organisational knowledge, and foster continuous learning (Al-Omoush, 2021). Its significance extends beyond enhancing conventional organisational performance to improving resource management and supporting business sustainability within the context of the Fourth Industrial Revolution (Mahmood & Mubarik, 2020; Paoloni et al., 2022). It facilitates organisational development by transforming traditional work into integrated knowledge-based activities, thereby strengthening organisations' capacity to adopt emerging technologies and respond proactively to environmental change (Alhosani & Ahmad, 2024; Trivedi &

Srivastava, 2023). Moreover, IC enhances competitive advantage and organisational productivity by driving innovation, facilitating the development of new products, and improving resource utilisation efficiency (Habib & Dalwai, 2023; Truong & Nguyen, 2024). It also strengthens business intelligence and digital transformation through the provision of organisational systems and infrastructures that improve strategic decision-making. Furthermore, IC promotes environmental innovation and sustainability by providing organisations with the knowledge capabilities required for continuous renewal, organisational adaptation, and balancing economic profitability with environmental responsibility (Khan et al., 2024; Villa et al., 2023). In addition, it supports sustainable entrepreneurship through innovation-oriented entrepreneurial capabilities that facilitate the development of knowledge-based competencies, the identification of sustainable business opportunities, the promotion of economic growth, and the reduction of unemployment (Ataei et al., 2024; Daskalopoulou et al., 2023; Yuksel, 2024).

Regarding its constituent dimensions, the tripartite classification proposed by Stewart (1997) has gained widespread acceptance in contemporary literature as the most robust theoretical framework for explaining the structure of IC (Abdelfattah et al., 2024; Paoloni et al., 2022). This framework comprises human capital, structural capital, and relational capital.

Human capital has its intellectual origins in the work of Adam Smith in 1776 and was subsequently advanced by Theodore Schultz in 1961 and Gary Becker in 1962, who conceptualised education and training as investments in human capabilities (Edeji, 2024; Isah Leontes & Hoole, 2024). Within business organisations, human capital refers to the collective stock of employees' competencies, skills, experience, expertise, and personal attributes that generate unique value and are difficult for competitors to replicate (Alakkas et al., 2023). It also encompasses employees' attitudes, innovative capabilities, commitment to organisational development, and environmental responsibility (Anser et al., 2024; Yuksel, 2024). Human capital contributes significantly to increased productivity, enhanced research and development activities, reduced organisational risks through improved governance, and diversified sources of organisational revenue (Abiwu & Martins, 2024; Song, 2024). Structurally, it consists of three core elements: competencies, behaviours, and cognitive agility (Siska Yuli et al., 2024).

The second component, structural capital, emerged prominently during the 1990s through the pioneering work of Leif Edvinsson and Michael S. Malone in 1997, together with Nick Bontis in 1998, who positioned it as a complementary resource to human capital (Oliko et al., 2024). Structural capital represents the stable organisational knowledge embedded within internal systems, operational processes, databases, patents, intellectual property rights, and organisational culture (Belmonte da Silva et al., 2021; Lavín Verástegui, 2020). Its principal advantage lies in its permanence within the organisation, even after employees leave, by transforming individuals' tacit knowledge into explicit organisational knowledge that can be documented, stored, and reused (Sugianto et al., 2023). Consequently, structural capital improves operational efficiency, reduces organisational costs and errors, and provides the infrastructure and environmentally sustainable practices necessary to support organisational resilience and long-term sustainability (Tekala et al., 2024).

Finally, relational capital originates from R. Edward Freeman's Stakeholder Theory in 1984, which argues that strong relationships founded upon trust and collaboration enhance managerial effectiveness and organisational performance (Ismail et al., 2024). Whereas human and structural capital primarily concern an organisation's internal capabilities, relational capital focuses on the knowledge generated through interactions with the external environment (Zamboni et al., 2024). This intangible resource encompasses corporate reputation, brand equity, strategic alliances, distribution networks, customer trust, customer satisfaction, and broader stakeholder relationships (Gallegos et al., 2021; Paoloni et al., 2022). Relational capital serves as the primary mechanism through which organisations gain access to scarce strategic resources, identify emerging market and entrepreneurial opportunities, and ultimately strengthen long-term organisational success and sustainable business performance (Aslam et al., 2023; Ghodbane & Alwehabie, 2023).

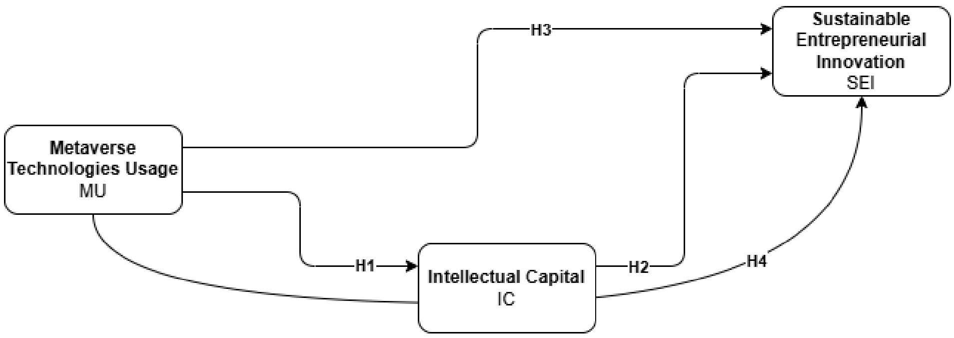
2.4 Conceptual Model and Hypothesis Development

Figure 1 presents the conceptual model of the current study. The model proposes that the use of metaverse technologies directly enhances IC and SEI within industrial organisations. It further posits that IC serves as a strategic organisational resource that positively influences SEI. Moreover, the model proposes that IC mediates the relationship between the use of metaverse technologies and SEI by transforming digitally generated knowledge, organisational capabilities, and collaborative resources into sustainable entrepreneurial outcomes. Collectively, the model explains how metaverse technologies contribute to SEI both directly and indirectly through the development of human, structural, and relational capital.

2.4.1 Actual Use of Metaverse Technologies in Industrial Organisations

The UTAUT is widely recognised as one of the most influential theoretical frameworks for explaining individuals' and organisations' adoption and use of emerging technologies (Venkatesh et al., 2012). The theory proposes that actual technology use represents the ultimate outcome of the interaction between several cognitive, behavioural, and organisational determinants, namely performance expectancy, effort expectancy, social influence, and facilitating conditions. These determinants jointly shape users' behavioural intention, which subsequently translates into actual usage behaviour.

Figure 1. The conceptual model of study



Source: *Authors' own work*

Among these determinants, performance expectancy is considered one of the strongest predictors of behavioural intention and technology adoption. Individuals are more likely to embrace metaverse technologies when they believe these technologies enhance operational efficiency, improve productivity, and reduce operational errors (Al-Adwan & Al-Debei, 2023; Ali et al., 2022). Similarly, effort expectancy plays a crucial role in shaping users' attitudes towards adoption, as the diverse forms of metaverse technologies are generally perceived as intuitive, user-friendly, and capable of minimising technical complexity while increasing users' confidence (Ma et al., 2025). Social influence further strengthens technology acceptance through encouragement from organisational leaders, technical experts, and colleagues who actively promote the integration of metaverse technologies into routine organisational practices (Jerin et al., 2025). In addition, facilitating conditions, including digital infrastructure, technical training, and governmental support, represent critical organisational resources that enable behavioural intention to be translated into actual technology use (Alkhwaldi et al., 2025).

Previous studies, such as Al-Emran et al. (2018) and Martins et al. (2014) indicate that individuals with strong behavioural intentions are more likely to exhibit preparatory behaviours, such as exploring the functionalities of emerging technologies and evaluating their performance, which constitute essential precursors to actual adoption. Furthermore, Williams et al. (2015) demonstrate that the relationship between behavioural intention and actual use is highly contingent upon the organisational and environmental context. Even strong behavioural intentions may fail to translate into actual usage when organisations lack adequate infrastructure or technical support. Conversely, the availability of facilitating conditions—including managerial support, technical training, and positive feedback following initial implementation—reinforces continued technology use and promotes its institutionalisation within organisational routines (Williams et al., 2015). Accordingly, behavioural intention functions as a behavioural activation mechanism encompassing several sequential stages, including motivational activation, usage planning, resource allocation, and responsiveness to a supportive organisational environment. When these stages operate within favourable organisational conditions, behavioural intention evolves into sustained and effective technology utilisation.

Within this theoretical framework, the actual use of metaverse technologies represents the final implementation stage in which favourable perceptions are transformed into tangible organisational practices within industrial organisations. Actual use extends beyond simply experimenting with the technology; rather, it involves integrating metaverse technologies into routine organisational activities, including virtual training, virtual product design, process simulation, and operational performance analysis (Quang & Tuamsuk, 2024). Such practical implementation enables industrial organisations to simulate complex manufacturing scenarios within immersive digital environments before deploying them in physical settings, thereby reducing operational costs and risks while enhancing sustainability through improved resource utilisation and energy efficiency (Yaseen et al., 2025). Moreover, actual technology use serves as an important indicator of an organisation's digital maturity (Williams et al., 2015), reflecting its ability to convert technological investments into measurable and sustainable operational performance.

Within the Iraqi industrial context, the actual use of metaverse technologies represents a strategic mechanism for overcoming challenges associated with resource scarcity and inadequate infrastructure. By providing flexible and cost-effective digital alternatives, metaverse technologies enable organisations to develop products, evaluate innovative technologies, and conduct virtual experimentation without incurring the substantial financial and operational risks associated with real-world implementation (Alfaiza et al., 2025; Yaseen et al., 2025). Consequently, their adoption expands opportunities to improve organisational performance and enhance productivity across critical industrial sectors, including manufacturing, energy production, and engineering industries.

Accordingly, the actual use of metaverse technologies should not be viewed merely as a technological application but rather as a manifestation of a broader strategic transformation in industrial business models. It reflects the integration of cognition, behavioural intention, and actual behaviour within the UTAUT framework, demonstrating organisations' ability to progress from conceptual acceptance to effective implementation. This transformation ultimately contributes to enhanced operational efficiency, green innovation, and long-term industrial sustainability (Al-Adwan et al., 2024; Dwivedi et al., 2017; Williams et al., 2015; Yaseen et al., 2025).

2.4.2 Metaverse Technologies and Intellectual Capital

The metaverse represents one of the most transformative innovations of the digital industrial era, providing an immersive virtual environment that integrates the physical and digital worlds to create interactive three-dimensional spaces for design, production, training, and real-time collaboration (Meng et al., 2025). The metaverse encompasses several core technological paradigms, including virtual worlds, which facilitate process simulation and workforce training (Vale et al., 2022); AR, which overlays interactive digital content onto physical environments to enhance operational understanding and control; mirror worlds, which accurately replicate physical systems and industrial equipment; and lifelogging, which systematically records users' activities and interactions (Cabrilo et al., 2024). The integration of these technologies enables industrial organisations to evaluate production-line performance, minimise operational errors and risks, and facilitate seamless cross-border collaboration (Mukaro et al., 2023). Consequently, the metaverse constitutes a strategic organisational capability that stimulates innovation, accelerates the transition towards intelligent and sustainable manufacturing, and serves as a comprehensive digital platform for enhancing all dimensions of IC (Cedrola et al., 2024).

Regarding the dimensions of IC, the metaverse plays a pivotal role in strengthening human capital by providing an immersive digital learning environment that supports experiential learning and interactive training while significantly reducing operational risks and training costs (Kour et al., 2025; Melnyk et al., 2021; Saman, 2025). These technologies, particularly digital twins, facilitate the transfer of organisational knowledge and preserve technical expertise across generations of employees (Hazrat et al., 2023). Furthermore, they foster organisational creativity by enabling multidisciplinary teams to collaboratively develop, test, and refine prototypes within immersive virtual environments, thereby accelerating innovation and improving decision-making processes (Kromidha et al., 2025; Yuksel, 2024). The metaverse also promotes workforce inclusivity by supporting remote training and employment opportunities while improving working conditions, enhancing employee commitment, and contributing to the sustainable management of human resources (Mukherjee et al., 2025; Paetow et al., 2025). These strategic contributions are consistent with Human Capital Theory and Organisational Learning Theory, both of which emphasise the importance of simulation-based learning and safe experimentation in developing employees' competencies, expertise, and innovative capabilities (Alsetoohy et al., 2024; Auerbach & Green, 2024; Saridakis et al., 2024).

From the perspective of structural capital, the metaverse fundamentally reshapes the knowledge infrastructure of industrial organisations by transforming tacit knowledge into documented and sustainable organisational assets embedded within information systems and organisational databases (Kim, 2021; Y. Wang et al., 2024). Through virtual environments, production systems can be monitored and managed in real time, creating a comprehensive digital memory that safeguards organisational knowledge against loss (Oliko et al., 2024; Sugianto et al., 2023). AR further enhances operational accuracy by providing technicians with real-time technical information and supporting interactive training systems that preserve best organisational practices (Anser et al., 2024; Fernandez-Jardón & Silva, 2020). Likewise, mirror worlds establish continuously evolving digital repositories and synchronised representations of physical systems that improve managerial decision-making (Ahmad & Aligarh, 2024; Mokhlis & Diop, 2024). Meanwhile, lifelogging technologies contribute to the continuity of organisational knowledge by reducing knowledge loss associated with employee retirement or turnover (Paetow et al., 2025). Collectively, these technological capabilities establish an integrated digital infrastructure that supports organisational sustainability while operationalising IC Theory through the continuous transformation of individual knowledge into organisational learning, knowledge renewal, and institutional memory (Alsetoohy et al., 2024; Omar et al., 2019; Radha et al., 2025).

With respect to relational capital, metaverse technologies fundamentally redefine organisational relationships and industrial collaboration by eliminating geographical and temporal barriers and enabling immersive real-time interaction (Mukaro et al., 2023; Zamboni et al., 2024). Virtual worlds enable organisations to host three-dimensional conferences, exhibitions, and collaborative events that strengthen strategic partnerships with investors, suppliers, and global business partners (AlQershi et al., 2020). Similarly, AR facilitates collaborative maintenance activities (Gallegos et al., 2021), real-time remote training between engineers and external experts, and immersive customer experiences that enhance customer satisfaction and loyalty (Mehralian et al., 2024; Xu & Wang, 2018). Mirror worlds improve operational transparency and supply chain coordination by enabling synchronised data exchange among stakeholders (Presutti et al., 2020), whereas lifelogging technologies systematically document collaborative interactions, thereby supporting future strategic decisions and preserving the digital memory of organisational relationships (Ramírez-Solis et al., 2022). Together, these technologies facilitate broader research and development networks, enable collaborative product development at lower costs, and support dialogue on sustainability initiatives with governmental and regulatory stakeholders (Ismail et al., 2024; Tian et al., 2022; Villanueva-Flores et al., 2022). Consistent with IC Theory, the metaverse transforms conventional contractual relationships into flexible, knowledge-based partnerships founded upon trust, transparency, and mutual value creation (Alsetoohy et al., 2024; Mukaro et al., 2023; Presutti et al., 2020). Based on this comprehensive analysis of the mechanisms through which various metaverse technologies influence the three dimensions of IC—human, structural, and relational capital—within industrial organisations, the following hypothesis is proposed:

H1: The use of metaverse technologies has a direct and positive effect on enhancing intellectual capital within industrial organisations.

2.4.3 Intellectual Capital and Sustainable Entrepreneurial Innovation

SEI has emerged as a contemporary managerial orientation that seeks to balance environmental, social, and economic objectives while emphasising proactiveness, risk-taking, and the identification of technological and environmental opportunities (Baber, 2023; Diepolder et al., 2024; Wu et al., 2023). Within this context, IC, through its portfolio of intangible knowledge-based resources, has become a fundamental driver for generating, institutionalising, and sustaining entrepreneurial innovation (Truong & Nguyen, 2024). Existing literature demonstrates a strong causal and complementary relationship between IC and SEI (Amaya et al., 2022; Madhala et al., 2024; Secundo et al., 2020). From the perspective of the RBV, IC constitutes a unique strategic resource that is valuable, rare, difficult to imitate, and capable of generating sustainable competitive advantage through continuous value creation. Likewise, Dynamic Capabilities Theory argues that organisations capable of continuously renewing and reconfiguring their knowledge resources are better positioned to adapt to rapidly evolving environmental, technological, and market conditions (Dixit et al., 2025; Jordao & Novas, 2022; Pitelis et al., 2023).

The direct contribution of human capital lies in its role as the primary catalyst for developing SEI. Employees possessing advanced knowledge, expertise, and creative capabilities are more capable of designing environmentally sustainable solutions, acquiring green competencies, adopting proactive entrepreneurial behaviours, and managing innovation-related risks efficiently and effectively (AlQershi et al., 2023; Antwi-Boateng et al., 2023; Awode & Oduola, 2024; Hu, 2021; Ramadana et al., 2025). Through their knowledge, creativity, and problem-solving abilities, highly skilled employees generate innovative ideas that enable organisations to respond proactively to sustainability challenges while maintaining long-term competitiveness.

Similarly, structural capital contributes by providing the organisational systems, operational processes, patents, and institutional mechanisms that codify knowledge and transform individual ideas into sustainable organisational practices. These knowledge infrastructures facilitate organisational learning, improve strategic decision-making, and integrate sustainability principles into the organisation's digital and operational architecture (Khalequzzaman et al., 2025; Sayed & Nefzi, 2024; Shahbaz et al., 2024; Shahbaz & Malik, 2025). Consequently, structural capital ensures that innovative knowledge is systematically preserved, disseminated, and continuously exploited throughout the organisation rather than remaining dependent upon individual employees.

From another perspective, relational capital serves as a strategic mechanism for expanding external partnerships, accessing green financing opportunities, and establishing collaborative networks based on trust with customers, suppliers, investors, and other stakeholders. These external relationships facilitate the exchange of knowledge, reduce the risks associated with environmentally oriented innovation projects, and accelerate the commercialisation of sustainable solutions (Long & Liao, 2022; Nawangsari et al., 2024; Zamboni et al., 2024). By strengthening inter-organisational collaboration and stakeholder engagement, relational capital enables organisations to acquire complementary resources and accelerate sustainable entrepreneurial initiatives.

The effectiveness of SEI is substantially enhanced when these three dimensions of IC operate in an integrated and complementary manner. Human capital generates innovative ideas and entrepreneurial initiatives; structural capital institutionalises, protects, and manages these innovations through formal organisational systems; and relational capital facilitates their implementation, diffusion, and commercial exploitation through strategic networks and collaborative partnerships (Khalequzzaman et al., 2025). Importantly, these synergistic effects extend beyond short-term organisational performance, establishing a long-term foundation for continuous organisational learning, knowledge accumulation, and sustainable innovation capabilities (Shahbaz & Malik, 2025). Contemporary management literature further reinforces this relationship by emphasising that IC, supported by environmentally oriented organisational systems and stakeholder relationships, constitutes a critical source of sustainable profitability and knowledge-based competitive advantage (Abdallah et al., 2024; Kimuam et al., 2025; Mulatsih, 2025; Rehman et al., 2021). Based on the foregoing theoretical arguments, the study proposes the following hypothesis:

H2: Intellectual capital has a direct and positive effect on enhancing sustainable entrepreneurial innovation within industrial organisations.

2.4.4 Metaverse Technologies and Sustainable Entrepreneurial Innovation

The metaverse has emerged as one of the most transformative digital innovations reshaping the nature of innovation within the industrial sector. By providing an immersive digital environment that integrates design, simulation, and real-time interaction, the metaverse enables organisations to develop more efficient operational solutions while accelerating the transition towards SEI, which integrates environmental considerations into production processes to achieve comprehensive organisational sustainability (Latino et al., 2024). Its strategic value lies in offering an integrated virtual environment where ideas can be conceived, tested, and refined in real time with minimal financial cost and operational risk. This capability significantly accelerates innovation processes while allowing organisations to evaluate energy consumption, assess alternative materials, and optimise production decisions before physical implementation, thereby supporting environmentally sustainable manufacturing practices (Lyu & Fridenfalk, 2024; Yoşumaz, 2024).

Within this context, the metaverse functions as an enabling platform for multiple forms of innovation. It promotes disruptive innovation by facilitating experimentation with unconventional technologies and business models, such as virtual factories and digitally integrated manufacturing ecosystems. Simultaneously, it advances sustainable innovation by enabling the design of environmentally friendly products and production systems that minimise waste and improve resource efficiency (Sze et al., 2024). Moreover, the metaverse provides an ideal environment for open innovation, overcoming geographical constraints and enabling seamless collaboration among industrial firms, universities, research institutions, and technical experts. Such collaboration enriches joint research and development activities while accelerating knowledge sharing and technological transfer (Falcke & Zobel, 2024; Nguyen & Voznak, 2024; Smith, 2024).

Furthermore, the influence of the metaverse extends beyond technological innovation to encompass managerial, operational, and environmental innovation. It enables organisations to redesign business processes, conduct immersive three-dimensional meetings, and develop advanced virtual training programmes that enhance employee creativity and organisational performance through real-time data analytics supported by AR technologies (Bayram, 2024; Yoşumaz, 2024). These analytical capabilities allow organisations to evaluate the efficiency of resource utilisation—including water and energy consumption—and assess the environmental impacts of production materials, thereby facilitating the adoption of sustainable circular business models (Assad et al., 2024). In addition, the metaverse stimulates marketing innovation by providing immersive product simulations that enable customers to experience products virtually before purchase. These experiences strengthen customer trust and brand loyalty while allowing organisations to evaluate marketing campaigns digitally, reducing advertising waste and promoting more responsible consumption patterns (Abbas et al., 2024; Athaide et al., 2024).

From a theoretical perspective, the relationship between metaverse technologies and SEI can be explained through Open Innovation Theory, which emphasises the importance of external collaboration and knowledge exchange in accelerating innovation processes (Falcke & Zobel, 2024). This perspective is further reinforced by Dynamic Capabilities Theory, which argues that organisations capable of sensing environmental changes and continuously reconfiguring their digital resources are better positioned to respond effectively to rapidly evolving technological and market conditions (Markopoulos et al., 2022). In practical terms, the innovation cycle within the metaverse follows an integrated sequence of activities that begins with opportunity identification, proceeds through digital solution design, and culminates in virtual testing and real-time performance evaluation prior to physical implementation. This iterative process substantially reduces innovation risks while ensuring that organisational processes generate positive environmental outcomes (Kruachottiku et al., 2023; Markopoulos et al., 2022). Thus, the metaverse represents a comprehensive strategic ecosystem that integrates operational excellence with environmental responsibility, enabling organisations to achieve sustainable competitive advantage within the digital economy. Based on this theoretical rationale, the following hypothesis is proposed:

H3: The use of metaverse technologies has a direct and positive effect on enhancing sustainable entrepreneurial innovation within industrial organisations.

2.4.5 Intellectual Capital as a Mediating Variable

Within the context of contemporary digital transformation, the metaverse has emerged as an immersive technological environment that fundamentally reshapes the mechanisms through which knowledge and operational solutions are generated in industrial organisations (Latino et al., 2024). However, transforming these extensive digital capabilities into SEI requires the presence of an intermediary organisational infrastructure in the form of IC, which functions as the strategic conduit through which virtual outputs are translated into tangible innovation capabilities, organised into valuable organisational knowledge, and ultimately commercialised (Truong & Nguyen, 2024; Wu et al., 2023). From the perspectives of Dynamic Capabilities Theory and the RBV, the metaverse represents a valuable technological asset that enables advanced simulation, experimentation, and energy-efficiency assessment without incurring material waste or excessive operational costs (Lyu & Fridenfalk, 2024; Yoşumaz, 2024). Nevertheless, the value generated by these digital capabilities can only be realised when IC effectively converts them into sustainable organisational outcomes.

At the first level of this mediating process, human capital serves as the primary mechanism through which employees recognise environmental opportunities, interpret digitally generated knowledge, and transform these insights into innovative solutions that simultaneously address environmental, social, and economic objectives (AlQershi et al., 2023; Antwi-Boateng et al., 2023; Ramadana et al., 2025). The immersive and interactive capabilities of the metaverse enhance employees' creativity, analytical capabilities, and environmental awareness, enabling them to develop and implement sustainable entrepreneurial solutions within real organisational settings.

Complementing this role, the metaverse continuously supplies organisations with real-time operational data and cost-efficient experimental environments that facilitate both disruptive and sustainable innovation (Kusi-Sarpong et al., 2022; Sze et al., 2024). Structural capital subsequently performs a critical mediating function by organising these digital inputs and transforming the environmental knowledge generated within virtual environments into formal organisational procedures, operational standards, and institutional routines. Without this intermediary mechanism, valuable digital information would remain confined within virtual simulations rather than being converted into collective organisational capabilities and measurable institutional performance (Sayed & Nefzi, 2024; Wu et al., 2023). Consequently, structural capital ensures that knowledge generated through metaverse technologies becomes embedded within the organisation's operational infrastructure and contributes to continuous organisational learning.

The mediating role of relational capital is equally significant. The metaverse facilitates unprecedented levels of cross-border collaboration and entrepreneurial interaction through immersive digital environments (Falcke & Zobel, 2024; Smith, 2024), thereby expanding organisations' strategic networks and strengthening collaborative partnerships founded on trust and knowledge sharing (Zamboni et al., 2024). Through these enhanced external relationships, relational capital enables organisations to access green financing opportunities, reduce innovation-related risks, accelerate the commercialisation of sustainable products and services, and promote responsible consumption practices, ultimately creating long-term competitive advantages (Athaide et al., 2024; Long & Liao, 2022; Nawangsari et al., 2024).

Thus, these complementary mechanisms demonstrate that metaverse technologies function as the technological enabler and knowledge-generation platform, whereas IC, through its human, structural, and relational dimensions, constitutes the organisational mechanism that assimilates digital knowledge and transforms it into SEI. This integrated perspective reinforces contemporary management literature, which argues that IC serves as the essential bridge linking advanced digital technologies with sustainable competitive performance by balancing innovation capabilities with environmental responsibility (Abdallah et al., 2024; Kimuam et al., 2025; Rehman et al., 2021). Accordingly, the influence of metaverse technologies on SEI is expected to operate through the development and mobilisation of IC as a strategic mediating mechanism. Based on this theoretical rationale, the following hypothesis is proposed:

H4: Intellectual capital mediates the positive relationship between the use of metaverse technologies and sustainable entrepreneurial innovation in industrial organisations.

3. Methodology

3.1 Data Collection and Sampling

The present study employed a deductive research approach grounded in the positivist research paradigm. This methodological orientation is particularly appropriate for empirically examining theoretically derived relationships among latent constructs and testing the proposed hypotheses using quantitative statistical techniques. The positivist perspective enables the objective measurement of organisational perceptions regarding the use of metaverse technologies, IC, and SEI, thereby facilitating rigorous empirical validation of the proposed conceptual framework.

The target population comprised organisations operating within the Iraqi industrial sector, including firms engaged in manufacturing, engineering, construction materials, food processing, chemicals, and other industrial activities. Since no comprehensive sampling frame covering all employees and managers within Iraqi industrial organisations was available, convenience sampling was adopted as the most appropriate non-probability sampling technique. This approach enabled the researchers to access respondents who possessed relevant organisational knowledge and practical experience regarding digital transformation initiatives, technological innovation, and strategic decision-making. The unit of analysis consisted of managers, assistant managers, information technology (IT) professionals, and administrative employees, as these organisational members are directly involved in technology adoption, knowledge management, and innovation-related activities within their respective organisations.

Data were collected using a structured questionnaire comprising two sections. The first section obtained respondents' demographic characteristics, including gender, job position, age, and years of professional experience, providing a comprehensive profile of the study participants and facilitating an assessment of sample representativeness. As presented in Table 1, the final sample consisted of 339 respondents, including 200 males (59.00%) and 139 females (41.00%). Regarding occupational roles, the respondents comprised 47 managers (13.86%), 75 assistant managers (22.12%), 105 IT professionals (30.97%), and 112 employees (33.04%). Most participants were between 34 and 42 years of age (38.64%), while the largest proportion reported 10–18 years of professional experience (32.74%), indicating that the sample consisted predominantly of experienced professionals occupying positions directly associated with organisational operations and technological implementation.

The second section of the questionnaire contained measurement items designed to assess the study constructs, namely metaverse technologies, IC, and SEI. All constructs were measured using previously validated scales adapted from the existing literature and modified where necessary to reflect the context of Iraqi industrial organisations. Respondents evaluated each statement using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

Because Arabic is the primary working language in Iraqi industrial organisations, the questionnaire was originally developed in Arabic to ensure conceptual clarity, linguistic accuracy, and consistent interpretation of the measurement items. Before large-scale data collection, the instrument underwent a comprehensive content validation process involving academic experts specialising in management, information systems, and innovation, together with experienced practitioners from the

Iraqi industrial sector. Their feedback contributed to improving the wording, contextual relevance, and overall content validity of the questionnaire.

The survey was administered in paper and electronically using Google Forms and distributed through professional networks, industrial organisations, managerial contacts, and relevant digital communication channels. Follow-up reminders were sent periodically to encourage participation and increase the response rate. Participation was entirely voluntary, and respondents were assured that their responses would remain anonymous and confidential and would be used exclusively for academic research purposes.

A total of 372 questionnaires were returned during the data collection period. After screening for incomplete questionnaires, inconsistent responses, and excessive missing data, 339 valid questionnaires were retained for the final statistical analysis, representing an effective response rate of approximately 91.1%. The final sample size exceeds the minimum requirements recommended for Partial Least Squares Structural Equation Modelling (PLS-SEM) and provides sufficient statistical power for simultaneously estimating both the direct and indirect (mediating) relationships specified in the proposed conceptual model. The demographic characteristics of the respondents are presented in Table 1.

3.2 Measurement of Constructs

The present study investigated three latent constructs, namely Metaverse Technologies Usage (MU), Intellectual Capital (IC), and Sustainable Entrepreneurial Innovation (SEI). All measurement scales were adapted from well-established studies in the literature and carefully modified to reflect the context of Iraqi industrial organisations. Minor wording revisions were introduced to improve clarity and contextual relevance while preserving the original conceptual meaning of the measurement items. Prior to data collection, the questionnaire was reviewed by academic experts and industry practitioners to ensure its content validity, linguistic accuracy, and practical applicability.

The construct of Metaverse Technologies Usage (MU) was conceptualised as the extent to which industrial organisations utilise immersive digital technologies—including VR, AR, digital twins, mirror worlds, lifelogging technologies, and virtual collaboration platforms—to support manufacturing, knowledge sharing, product development, training, and organisational decision-making. The measurement scale consisted of six items adapted from previous studies investigating metaverse adoption, immersive technologies, and digital transformation (Aiolfi & Luceri, 2024; Contreras et al., 2022; Meng et al., 2025; Mukaro et al., 2023; Yaseen et al., 2025).

Intellectual Capital (IC) was operationalised as a higher-order organisational capability comprising human capital, structural capital, and relational capital. The construct was measured using six items reflecting employees' competencies, organisational knowledge systems, learning capabilities, collaborative relationships, and knowledge-sharing practices. The measurement items were adapted from established IC literature (Abdelfattah et al., 2024; Jordao & Novas, 2022; Paoloni et al., 2022; Truong & Nguyen, 2024).

Table 1. Respondents' demographics.

Categories	Details	#	%
Gender	*Male*	200	59.00
	Female	139	41.00
Job position	*Manager*	47	13.86
	Assistant Manager	75	22.12
	IT professional	105	30.97
	Employee	112	33.04
Age (#years)	*Less than 25*	36	10.62
	25 – 33	75	22.12
	34 – 42	131	38.64
	53 – 61	68	20.06
	More than 61	29	8.55
Job Experience (#years)	*Less than 1*	35	10.32
	Less than 10	52	15.34
	10 – 18	111	32.74
	19 – 27	97	28.61
	More than 27	44	12.98

Notes: *N=339*
Source: *Authors' own work*

The dependent construct, Sustainable Entrepreneurial Innovation (SEI), was measured using six items capturing organisations' ability to develop environmentally sustainable products, improve operational processes, implement innovative business models, and balance economic, environmental, and social objectives. These items were adapted from previous studies on sustainable innovation, green entrepreneurship, and entrepreneurial orientation (Baber, 2023; Freudenreich et al., 2019; Osei Opoku et al., 2024; Terán-Yépez et al., 2020; Truong & Nguyen, 2024).

3.3 Data Analysis Strategy

The collected data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) implemented through SmartPLS version 3.2.9. PLS-SEM is widely acknowledged as one of the most appropriate multivariate analytical techniques for examining complex relationships among latent constructs measured by multiple indicators, particularly when the primary objective is prediction, theory extension, and the explanation of variance in endogenous variables (Hair & Alamer, 2022). Given that the proposed research model incorporates direct and indirect (mediating) relationships among metaverse technologies, IC, and SEI, PLS-SEM provides a robust methodological framework for evaluating the proposed hypotheses.

The selection of PLS-SEM was supported by several methodological considerations. First, the conceptual model comprises multiple latent constructs linked through both direct and mediation effects, resulting in a relatively sophisticated structural framework that is well suited to variance-based structural equation modelling (Hair & Alamer, 2022). Specifically, the study examines the direct influence of metaverse technologies on IC and SEI, the effect of IC on SEI, and the mediating role of IC in explaining the relationship between metaverse technologies and SEI. Such a model requires the simultaneous estimation of multiple interdependent relationships, making PLS-SEM an appropriate analytical technique.

Second, PLS-SEM enables the concurrent assessment of both the measurement model and the structural model within a single analytical procedure. This capability allows researchers to evaluate indicator reliability, internal consistency reliability, convergent validity, discriminant validity, collinearity, coefficient of determination (R^2), effect sizes (f^2), and the significance of hypothesised structural relationships simultaneously (Hair & Alamer, 2022). Moreover, PLS-SEM is particularly effective in estimating mediation models using non-parametric bootstrapping procedures, thereby providing robust statistical evidence for both direct and indirect effects.

Third, PLS-SEM is especially suitable for studies examining emerging digital technologies and organisational innovation, where theoretical models frequently involve multiple interconnected constructs and prediction-oriented objectives. As the present study seeks to explain how the use of metaverse technologies contributes to SEI both directly and indirectly through IC, PLS-SEM offers the methodological flexibility required to evaluate these complex causal mechanisms.

The final dataset consisted of 339 valid responses collected from managers, assistant managers, IT professionals, and employees working in Iraqi industrial organisations. This sample size exceeds the minimum recommendations for PLS-SEM analysis and provides adequate statistical power for estimating the proposed structural model and testing both the direct and mediating relationships among the study variables. Consequently, PLS-SEM was considered the most appropriate analytical approach for validating the measurement model, estimating the structural model, and empirically testing the proposed research hypotheses.

4. Results

4.1 Measurement Model Assessment

Prior to testing the proposed hypotheses, the measurement model was evaluated to establish the reliability, validity, and collinearity of the latent constructs. Following the recommendations of

Hair and Alamer (2022), the assessment included internal consistency reliability, convergent validity, discriminant validity, and collinearity diagnostics.

Internal consistency reliability and convergent validity were examined using Cronbach's alpha (α), rho_A, Composite Reliability (CR), and the Average Variance Extracted (AVE). As reported in Table 2, all measurement properties exceeded the recommended threshold values. Cronbach's alpha coefficients ranged from 0.926 to 0.947, substantially exceeding the minimum acceptable value of 0.70, thereby demonstrating excellent internal consistency among the measurement items. Likewise, rho_A values ranged between 0.926 and 0.947, further confirming the stability and reliability of the measurement scales. Composite Reliability values varied from 0.947 to 0.962, indicating a high degree of internal consistency across all constructs. Among the three constructs, IC exhibited the highest reliability (CR = 0.962), followed by SEI (CR = 0.958) and Metaverse Technologies (CR = 0.947).

Table 2. Convergent validity

Constructs	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
SEI	0.941	0.942	0.958	0.849
IC	0.947	0.947	0.962	0.863
MU	0.926	0.926	0.947	0.818

Source: *Authors' own work*

Convergent validity was assessed through the Average Variance Extracted (AVE). As shown in Table 2, AVE values ranged from 0.818 to 0.863, substantially exceeding the recommended threshold of 0.50 (Hair & Alamer, 2022). Specifically, IC achieved the highest AVE (0.863), followed by SEI (0.849) and Metaverse Technologies (0.818). These findings indicate that each construct explains well over half of the variance of its corresponding indicators, thereby providing strong evidence of convergent validity.

Discriminant validity was subsequently evaluated using both the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio (HTMT), as presented in Table 3. According to the Fornell–Larcker criterion, the square root of the AVE for each construct (displayed on the diagonal in bold) should exceed its correlations with all other constructs. This requirement was fully satisfied. The square roots of the AVE were 0.922 for SEI, 0.929 for IC, and 0.905 for Metaverse Technologies, all of which were greater than the corresponding inter-construct correlations. Furthermore, the HTMT values (shown above the diagonal in italics) ranged from 0.515 to 0.687, remaining well below the conservative threshold of 0.85, thereby providing additional evidence that the three constructs are empirically distinct and capture separate conceptual domains.

To further verify the adequacy of the measurement model, collinearity diagnostics were conducted using the Variance Inflation Factor (VIF). As reported in Table 4, the outer VIF values ranged from 2.873 to 4.875 across all measurement indicators. More specifically, the indicators of Metaverse Technologies recorded VIF values between 2.873 and 3.774, those of IC ranged from 3.758 to 4.875, and the indicators of SEI ranged between 3.557 and 4.160. All values remained below the recommended threshold of 5.00, indicating that indicator multicollinearity was not a concern (Hair & Alamer, 2022). Similarly, the inner VIF values assessing collinearity among the predictor constructs ranged from 1.000 to 1.495, substantially below the recommended cut-off value of 3.30, thereby confirming the absence of structural multicollinearity within the proposed research model.

Table 3. Discriminant validity

Constructs	SEI	IC	MU
SEI	**0.922**	*0.687*	*0.515*
IC	0.649	**0.929**	*0.614*
MU	0.481	0.575	**0.905**

***Notes: Bold number*= √*AVE*,** *Italic numbers=HTMT*
Source: *Authors' own work*

Table 4. Variance Inflation Factors

Items	Outer VIF	Items	Outer VIF	Items	Outer VIF
MU_item1	3.774	IC_item1	4.875	SEI_item1	4.160
MU_item2	3.121	IC_item2	4.721	SEI_item2	3.557
MU_item3	3.248	IC_item3	3.758	SEI_item3	3.681
MU_item4	2.873	IC_item4	3.875	SEI_item4	4.050
Inner VIF	**SEI**	**IC**			
IC	1.495				
MU	1.495	1.000			

Source: *Authors' own work*

Thus, the findings demonstrate that the measurement model possesses excellent psychometric properties. The constructs exhibit high internal consistency reliability, strong convergent validity, satisfactory discriminant validity, and no evidence of problematic collinearity. Consequently, the measurement model provides a robust empirical foundation for evaluating the structural model and testing the proposed direct and mediating hypotheses.

4.2 Structural Model Assessment

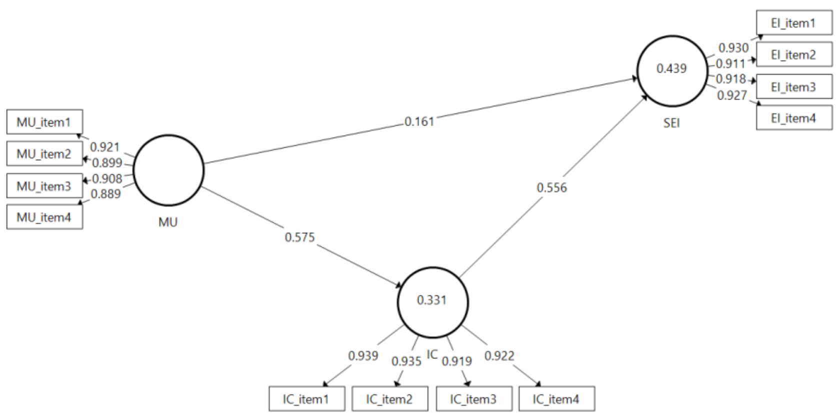
Following the validation of the measurement model, the structural model was assessed to examine the proposed direct and indirect relationships among Metaverse Technologies Usage (MU), Intellectual Capital (IC), and Sustainable Entrepreneurial Innovation (SEI). Hypothesis testing was conducted using the bootstrapping procedure in SmartPLS, and the results, including the standardized path coefficients (β), standard deviations (SD), t-statistics, p-values, effect sizes (f^2), and coefficients of determination (R^2), are presented in Table 5. The corresponding structural model is illustrated in Figure 2.

Table 5. The path analysis of study model

Relationships	β	SD	T Statistics	P Values	f^2	R^2	Results?
MU → IC	0.575	0.034	16.808	0.000	0.495	0.331	*Accept*
IC → EI	0.556	0.044	12.623	0.000	0.369		*Accept*
MU → EI	0.161	0.050	3.229	0.001	0.031	0.439	*Accept*
MU → IC → EI	0.320	0.032	10.087	0.000	0.864		*Accept*

Note: *β = Standard regression, SD = Standard Deviation.*
NFI = 0.951, SRMR = 0.031
Source: *Authors' own work*

Figure 2. The structural model of study



Source: *Authors' own work*

The findings provide strong empirical support for the proposed conceptual framework. First, Metaverse Technologies exert a significant positive effect on IC (H1: β = 0.575, t = 16.808, $p < 0.001$), indicating that greater organisational utilisation of metaverse technologies substantially enhances the development of human, structural, and relational capital within industrial organisations. The effect size was large ($f^2 = 0.495$), suggesting that metaverse technologies represent an important strategic driver of IC. Furthermore, the model explains 33.1% of the variance in IC ($R^2 = 0.331$), indicating a moderate level of explanatory power.

Second, IC demonstrates a significant positive influence on SEI (H2: $\beta = 0.556$, $t = 12.623$, $p < 0.001$). This finding confirms that organisations possessing stronger knowledge resources, organisational capabilities, and stakeholder relationships are better positioned to develop environmentally responsible entrepreneurial innovations. The corresponding effect size ($f^2 = 0.369$) indicates a substantial practical influence of IC on SEI.

The analysis also reveals that Metaverse Technologies have a direct positive effect on SEI (H3: $\beta = 0.161$, $t = 3.229$, $p = 0.001$). Although statistically significant, this relationship exhibits a relatively small effect size ($f^2 = 0.031$), suggesting that the direct contribution of metaverse technologies to SEI is comparatively modest when considered independently. Nevertheless, this result demonstrates that digital immersive technologies contribute directly to organisational innovation by facilitating virtual collaboration, experimentation, simulation, and environmentally sustainable production practices.

The mediating role of IC was subsequently examined. As reported in Table 5, the indirect relationship between Metaverse Technologies and SEI through IC is positive and highly significant (H4: $\beta = 0.320$, $t = 10.087$, $p < 0.001$). Moreover, the indirect effect exhibits a very large effect size ($f^2 = 0.864$), indicating that IC represents the principal organisational mechanism through which the benefits of metaverse technologies are translated into SEI. The simultaneous significance of both the direct and indirect effects suggests the existence of complementary partial mediation, whereby metaverse technologies influence SEI both directly and indirectly through the enhancement of IC.

Regarding the explanatory capability of the model, the coefficient of determination indicates that 43.9% of the variance in SEI is explained jointly by Metaverse Technologies and IC ($R^2 = 0.439$). According to commonly accepted guidelines for PLS-SEM, this value represents moderate explanatory power, demonstrating that the proposed model explains a substantial proportion of the variance in SEI among Iraqi industrial organisations.

Thus, the structural model provides strong empirical evidence supporting all four proposed hypotheses. The findings suggest that the adoption of metaverse technologies not only strengthens IC directly but also enhances SEI both independently and, more importantly, indirectly through the development of organisational knowledge resources. These results underscore the strategic importance of integrating immersive digital technologies with IC development to achieve long-term sustainable innovation within industrial organisations.

4.3 Model Fit Indices

The overall adequacy of the proposed structural model was evaluated using the Standardised Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI). As reported in Table 5, the model achieved an SRMR value of 0.031, which is substantially below the recommended threshold of 0.08, indicating a very good level of model fit and a minimal discrepancy between the observed and model-implied covariance matrices (Hair & Alamer, 2022). Similarly, the model produced an NFI value of 0.951, exceeding the recommended benchmark of 0.90, thereby demonstrating an excellent overall fit between the proposed theoretical model and the empirical data. Collectively, these goodness-of-fit indices confirm that the structural model adequately represents the underlying relationships among Metaverse Technologies, IC, and SEI.

In the light of above, the satisfactory model fit, the strong psychometric properties of the measurement model, and the statistically significant structural relationships provide robust empirical support for the proposed conceptual framework. These findings confirm the suitability of the model for explaining how metaverse technologies contribute to SEI through the strategic development of IC within Iraqi industrial organisations.

5. Discussion

The findings of this study provide robust empirical evidence supporting the proposed conceptual model and reinforce the growing importance of metaverse technologies as strategic digital capabilities that enhance IC and foster SEI within industrial organisations. Specifically, all four hypotheses were supported, demonstrating that metaverse technologies contribute to SEI both directly and indirectly through the development of IC. These findings are consistent with the theoretical assumptions of the UTAUT, the RBV, Dynamic Capabilities Theory, and IC Theory, collectively explaining how digital technologies are transformed into sustainable organisational outcomes.

The significant positive relationship between metaverse technologies and IC (H1) indicates that organisations adopting immersive technologies are better able to develop and leverage their human, structural, and relational capital. The relatively large path coefficient ($\beta = 0.575$) and effect size ($f^2 = 0.495$) suggest that metaverse technologies extend beyond operational digitalisation to become strategic enablers of organisational knowledge creation. This finding supports previous studies arguing that immersive environments facilitate experiential learning, collaborative knowledge exchange, and organisational memory through VR, digital twins, mirror worlds, and AR (Alsetoohy et al., 2024; Cedrola et al., 2024; Hazrat et al., 2023; Mukaro et al., 2023). From the perspective of UTAUT, the actual use of metaverse technologies enables employees to integrate digital knowledge into everyday organisational practices, while Human Capital Theory explains how immersive learning environments enhance employees' competencies and innovation capabilities (Auerbach & Green, 2024; Saridakis et al., 2024). The findings therefore suggest that industrial organisations adopting metaverse technologies establish stronger knowledge infrastructures capable of supporting long-term organisational competitiveness.

The results further demonstrate that IC significantly enhances SEI (H2). The strong positive relationship ($\beta = 0.556$) confirms that IC represents one of the most valuable strategic resources for achieving environmentally responsible entrepreneurial outcomes. This finding aligns closely with the Resource-Based View, which considers knowledge-based resources to be valuable, rare, difficult to imitate, and essential for sustainable competitive advantage (Jordao & Novas, 2022; Pitelis et al., 2023). The findings also corroborate previous research demonstrating that human capital stimulates creativity and green problem-solving, structural capital institutionalises innovation through organisational systems and routines, and relational capital accelerates innovation through stakeholder collaboration and external knowledge exchange (Amaya et al., 2022; Khalequzzaman et al., 2025; Long & Liao, 2022; Truong & Nguyen, 2024). Consequently, IC should be viewed not merely as an intangible organisational asset but as a strategic capability that transforms organisational knowledge into sustainable entrepreneurial value.

The direct positive effect of metaverse technologies on SEI (H3) provides further evidence that immersive digital technologies stimulate innovation independently of other organisational capabilities. Although the effect size was comparatively modest ($\beta = 0.161$; $f^2 = 0.031$), its statistical significance indicates that metaverse technologies directly facilitate sustainable innovation by enabling virtual experimentation, digital prototyping, resource optimisation, and environmentally conscious decision-making. These findings are consistent with recent studies suggesting that immersive digital ecosystems enhance open innovation, virtual collaboration, sustainable manufacturing, and circular business models (Falcke & Zobel, 2024; Latino et al., 2024; Markopoulos et al., 2022; Sze et al., 2024; Yoşumaz, 2024). The relatively smaller direct effect further implies that digital technologies alone are insufficient to maximise sustainable innovation unless supported by complementary organisational capabilities.

This interpretation is reinforced by the findings for H4, which reveal that IC significantly mediates the relationship between metaverse technologies and SEI ($\beta = 0.320$, $t = 10.087$). The substantial indirect effect demonstrates that the principal value of metaverse technologies is realised through their ability to strengthen organisational knowledge resources before generating innovation outcomes. This finding strongly supports Dynamic Capabilities Theory, which argues that technological resources create value only when organisations possess the capabilities required to sense opportunities, integrate knowledge, and continuously reconfigure organisational resources (Dixit et al., 2025; Markopoulos et al., 2022; Pitelis et al., 2023). Likewise, the result extends previous studies that identified IC as the organisational mechanism linking digital transformation with sustainable performance (Abdallah et al., 2024; Kimuam et al., 2025; Rehman et al., 2021; Wu et al., 2023). Accordingly, metaverse technologies should not be regarded merely as advanced digital infrastructures but rather as strategic knowledge-generation platforms whose innovation potential depends largely on organisations' ability to develop and mobilise human expertise, institutional knowledge systems, and collaborative stakeholder networks.

6. Conclusion

This study examined the relationships among metaverse technologies, IC, and SEI within Iraqi industrial organisations. Using PLS-SEM, the findings confirmed that the actual use of metaverse technologies significantly enhances IC and directly promotes SEI. Furthermore, IC was found to exert a strong positive influence on SEI while simultaneously acting as a significant mediating mechanism between metaverse technologies and innovation outcomes. These results demonstrate that immersive digital technologies create the greatest organisational value when combined with well-developed human, structural, and relational capital. Consequently, the study highlights that SEI is not driven solely by technological investment but also by organisations' ability to transform digital capabilities into knowledge-based strategic assets. Overall, the proposed framework provides empirical evidence that integrating metaverse technologies with IC development represents an effective pathway towards achieving sustainable competitiveness and long-term innovation performance in the industrial sector.

6.1 Theoretical Implications

This study makes several important theoretical contributions to the literature on digital transformation, IC, and sustainable innovation. First, it extends the UTAUT beyond technology adoption by demonstrating that the actual use of metaverse technologies generates strategic organisational outcomes through the development of IC. Second, by integrating the RBV, Dynamic Capabilities Theory, and IC Theory into a unified conceptual framework, the study provides a more comprehensive explanation of how advanced digital technologies create sustainable entrepreneurial value. Third, the empirical confirmation of the mediating role of IC contributes to the growing literature on digital transformation by demonstrating that technological capabilities alone are insufficient to achieve sustainable innovation unless they are effectively translated into human expertise, organisational knowledge systems, and collaborative stakeholder relationships. Finally, the study enriches the emerging metaverse literature by providing empirical evidence from the industrial sector of a developing economy, thereby expanding the theoretical understanding of metaverse-enabled organisational innovation beyond consumer, education, and entertainment contexts.

6.2 Practical Implications

The findings offer several practical implications for managers, policymakers, and industrial organisations seeking to accelerate digital transformation and sustainable innovation. Industrial managers should regard metaverse technologies as strategic organisational capabilities rather than merely digital tools by integrating VR, AR, digital twins, and immersive collaboration platforms into product development, employee training, process optimisation, and sustainable manufacturing initiatives. Simultaneously, organisations should invest in strengthening human capital through continuous digital skills development, structural capital through integrated knowledge management systems and digital repositories, and relational capital through strategic partnerships with universities, technology providers, suppliers, and government agencies. Policymakers should support the diffusion of metaverse technologies by improving digital infrastructure, encouraging industrial digitalisation programmes, and providing incentives for innovation-oriented investments. Furthermore, national industrial strategies should promote collaboration between academia and industry to facilitate knowledge transfer and the development of digital competencies. By aligning technological investment with IC development, industrial organisations can improve operational efficiency, accelerate SEI, strengthen environmental performance, and enhance long-term competitiveness in the digital economy.

7. Limitations and Future Research Directions

Despite its theoretical and practical contributions, this study has several limitations that should be acknowledged when interpreting the findings. First, the study adopted a cross-sectional research design, which captures respondents' perceptions at a single point in time. Consequently, although the proposed relationships are theoretically grounded and statistically significant, causal inferences should be interpreted with caution. Longitudinal studies would provide a more comprehensive understanding of how the adoption of metaverse technologies and the development of IC evolve over time and influence SEI. Second, the research relied on self-reported questionnaire data, which may be subject to common method bias and respondents' perceptual bias despite the satisfactory reliability and validity of the measurement model. Future studies could combine perceptual data with objective organisational indicators, such as innovation outputs, patent applications, environmental performance metrics, digital maturity indices, or financial performance, to strengthen the robustness and external validity of the findings.

Third, the study focused exclusively on industrial organisations operating in Iraq. Although this context provides valuable insights into digital transformation within a developing economy, the institutional, technological, and cultural characteristics of Iraq may limit the generalisability of the findings to other countries and industrial settings. Future research should replicate the proposed model across different countries, industries, and economic contexts to assess its cross-cultural applicability and external validity. Fourth, the present study examined IC as the sole mediating mechanism linking metaverse technologies and SEI. While IC explained a substantial proportion of the indirect effect, other organisational capabilities may also play important mediating or moderating roles. Future studies are encouraged to incorporate variables such as knowledge management capability, organisational learning, digital transformation capability, organisational agility, absorptive capacity, innovation capability, environmental orientation, or dynamic capabilities to develop more comprehensive explanatory models. Furthermore, future research may investigate the individual dimensions of IC—human capital, structural capital, and relational capital—as separate mediators rather than treating IC as a higher-order construct. Such an approach would provide deeper insights into the specific mechanisms through which metaverse technologies generate SEI.

Finally, as metaverse technologies continue to evolve rapidly through advances in AI, digital twins, blockchain, XR, and Industry 5.0, future studies should examine how these complementary technologies jointly influence organisational sustainability, circular economy practices, smart manufacturing, and digital entrepreneurship. Comparative studies between developed and developing economies, longitudinal investigations, and multi-level research designs would further enrich the emerging body of knowledge on metaverse-enabled innovation and provide stronger evidence regarding the long-term organisational and societal impacts of immersive digital technologies.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Authors' contributions

All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published this version of the manuscript.

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Data availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Appendix A. Study's Questionnaire Items

A. Metaverse Technologies Usage (MU)

MU1. Our organisation uses immersive virtual technologies (e.g., VR/AR) to improve operational processes. MU2. Metaverse technologies facilitate collaboration and knowledge sharing among employees. MU3. Digital twins and virtual simulations are used to improve production planning and operational decision-making. MU4. The metaverse enables our organisation to test products and production processes before physical implementation.

B. Intellectual Capital (IC)

IC1. Employees in our organisation possess the knowledge and skills required to support innovation. IC2. Our organisation effectively captures and shares knowledge among employees. IC3. Our organisation continuously improves its internal processes through organisational learning. IC4. Intellectual knowledge is effectively utilised to improve organisational performance.

C. Sustainable Entrepreneurial Innovation (SEI)

SEI1. Our organisation continuously develops environmentally sustainable products or services. SEI2. We regularly introduce innovative production processes that reduce resource consumption. SEI3. Our organisation actively explores new business opportunities based on sustainability principles. SEI4. Sustainable innovation has become an integral part of our long-term organisational strategy.

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