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Navigating the Metaverse: Exploring the Impact on Building Performance and Operations, Decarbonization, and Human Wellbeing

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ABSTRACT
The emerging Metaverse, despite its current state of infancy, is positioned to seamlessly integrate into our everyday lives, exerting transformative influence across various sectors, unlocking commercial prospects, and augmenting overall well-being. This investigation delves into the potential benefits and drawbacks inherent in utilizing the metaverse to optimize building performance, particularly with regards to well-being, health, and resource efficiency. As we endeavor to achieve the ambitious objective of decarbonizing buildings and attaining Net Carbon Neutral or Net Carbon Zero status, this research underscores the pivotal role of digital transformation, machine learning, and comprehensive human education in harnessing opportunities. Furthermore, the study addresses critical concerns pertaining to health implications and significant carbon emissions linked to AI model training, offering a comprehensive exploration of the metaverse's impact on sustainable and efficient building practices.
KEYWORDS;-*Mixed reality, multi-user virtual environments, artificial intelligence, indoor environment quality, energy efficiency, virtual reality, and health and wellness*

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I. INTRODUCTION

Web 1.0 constrained users to a passive role, imposing limitations on interactions to the act of perusing or observing unchanging content on websites. The advent of Web 2.0 brought forth a paradigm shift, introducing interactive and user-centric characteristics to the World Wide Web. Presently, as we contemplate the progression towards Web 3.0, the notion of the Metaverse emerges, seamlessly merging virtual and tangible realms into decentralized, multi-user platforms. This transition enables multisensory engagements within dynamic, frequently three-dimensional (3D) environments, empowering users to encounter real-time existence [1,2].The term "Metaverse" gained prominence in 2020, although its application in scientific research remains at an early stage. In the meantime, the "built environment" encompasses the physical backdrop of our daily lives, encompassing structures, infrastructure, and networks that shape our activities.This research paper delves into the potential applications and uncertainties surrounding the Metaverse within the interdisciplinary realms of the built environment, spanning building design, operations, maintenance, and health and wellness. Its objective is to explore how the Metaverse can actively intervene through cognitive digital twin environments, exerting influence over both the virtual and physical worlds.

II. UNDERSTANDING OF BUILT ENVIRONMENT, HEALTH AND WELLNESS, INDOOR ENVIRONMENTAL QUALITY AND RESOURCE EFFICIENCY

A considerable proportion of greenhouse gases in the atmosphere, amounting to 40%, originate from the constructed environment. Given that individuals spend a significant portion, more than 90%, of their lives indoors [3], the effectiveness of these structures holds substantial influence over physical, mental, and emotional well-being, as well as the long-term durability of physical assets [4-5]. It is rather surprising, however, that the focus on building renovations, which represent over half of the revenue for the American Institute of Architects (AIA), primarily emphasizes aesthetics and functionality, allocating a mere 3.8% towards enhancing energy performance and a scant 1.6% to improve resilience. This contributes significantly to the carbon footprint during a critical climate crisis. In this context, the emergence of the Metaverse presents a potential solution to mitigate these emissions.In today's society, where an increasing amount of time is spent indoors, especially among the younger generation referred to as the "indoor generation," concerns regarding associated physical issues are becoming more prominent [6]. The Whitehall II Study conducted by Marmot and colleagues [7] underscores that the impact of physical surroundings on mental health extends beyond the avoidance of Sick Building Syndrome (SBS). Employers and Building Management Departments (BMDs) must consider broader factors, including job structures and employee autonomy, in order to foster a healthier lifestyle[8].Considering the expected rise in the burden of non-communicable diseases due to longer working lives and increasing life expectancies, lifestyle factors such as smoking, poor diet, and physical inactivity play a crucial role. The Metaverse, with its potential to educate and inspire healthy living, becomes a powerful tool in controlling and modifying these risk factors [9].However, it is important not to overlook the environmental impact of Metaverse technologies. Projections indicate significant carbon emissions resulting from the use of OpenAI's GPT-3 and Meta's OPT, with estimations of over 500 and 75 metric tonnes of carbon dioxide released, respectively. Moreover, the utilization of cloud computing, which is integral to online gaming, virtual reality, and high-resolution image processing, further exacerbates these emissions. Therefore, responsible management of the environmental consequences of the Metaverse is of utmost importance.

III. LITERATURE REVIEW

Because they perceive the potential benefits for strategic empowerment, investors and building owners are keen to incorporate emerging technologies like augmented reality, blockchain, extended reality, and artificial intelligence. Metaverse is one of the technology disruptions that the built environment (BE) sector and the greater business community are paying attention to. [10-13]

The hyperconnected digital universe known as the metaverse has the potential to drastically change how building designers, operators, and business interactions are carried out in the future built environment in a world where several virtual realities collide. The potential of the metaverse is growing as more individuals spend time due to extensive digitalization of business processes and greater adoption of business to business (B2) integration. Enterprises are also allocating substantial resources towards the advancement of metaverse methodologies. The fundamental elements of the constructed environment have been influenced by various metaverse strategies. Research on functional metaverse is currently lacking.

The objective of this article is to offer a comprehensive examination of the incorporation of metaverse methodologies for many stakeholders involved in the built environment. The assessment identifies a number of areas that need additional investigation into the BE-metaverse ecosystem, such as boosting the accuracy of point cloud data for as-built models of current facilities, strengthening data interoperability, design for cybersafety (e-safety), Sustainability and creating effective virtual real-estate operation and managment integration.

IV. POSSIBILITIES AND UNCERTAINITIES

The term "metaverse" denotes a parallel, three-dimensional (3-D) virtual reality that permeates the entirety of digital technology, poised to revolutionize how we live, play, study, and work in the tangible world.The initial phase of the internet, known as Web 1.0, primarily showcased static webpages with limited user interaction or user-generated content. The transition to Web 2.0 in the 90s introduced improved user interfaces and experiences, alongside user-generated content, paving the way for blogs and social media platforms. This progression led to a vast network of interconnected websites and information. Envisioning a departure from the dominance of technology giants, Web 3.0 utilizes decentralized blockchain technology, tokens, and Decentralized Finance (DeFi) to establish dependable, secure, and immersive decentralized web platforms, content, and services [10].In traversing a Metaverse-driven world, where digital interactions are incessant, prioritizing human connection necessitates deliberate curation. Acknowledging that Homo Sapiens are inherently wired for interaction and societal progress, the key to achieving success lies in fostering connection, communication, and trust (CCT) as the three pivotal drivers of success. Disregarding the significance of CCT may lead to resistance to change, posing substantial risks to the overall outcome and the quality of the user experience in this new era of the Metaverse.

V. OPPORTUNITIES

In recent times, there has been a profound transformation in the fields of education and healthcare. The realm of education, which used to be conventional, has now incorporated immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR). Moreover, the emergence of brain-to-computer interfaces has opened up new possibilities in terms of cognitive interaction.Immersive technologies, especially in the realm of training and education, have become indispensable. The utilization of mixed reality (MR) for presenting information has proven to be more effective in terms of retention compared to traditional two-dimensional screens. The digital domain offers customized training environments, thereby eliminating the need for physical laboratories and associated resources. This contributes to the objective of achieving net-zero carbon emissions.Within the educational metaverse, three crucial elements intersect: the student, their temporal and spatial context, and the learning experience. Zheng et al. [14] propose a unique framework for collective intelligence in the educational metaverse, driven by data and knowledge. Although still in its early stages, smart services within the educational metaverse are currently being explored.The global transition to virtual education in response to the COVID-19 pandemic has resulted in a significant reduction in carbon emissions, as physical visits to campuses became impractical. This unintended environmental benefit highlights the potential of digital education models.To illustrate the transformative impact of technology in education, the Ministry of Education (MOE) in Singapore introduced the Adaptive Learning System for mathematics in June 2023. This system, which focuses on Primary 5 subjects, utilizes artificial intelligence (AI) and machine learning to generate personalized learning recommendations based on student responses. By incorporating AI as a pre-learning tool, students can engage with subjects before formal instruction, enabling educators to tailor their classes based on feedback and data collected by AI. This innovative approach harnesses technology to enhance both teaching and learning experiences in the educational landscape.

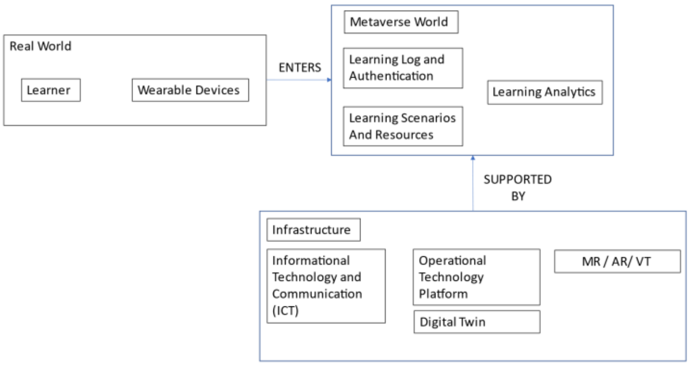

Figure 1: Metaverse Features for Learning and Education Platform

Within the expansive metaverse universe, individuals armed with Web 3.0 access can collaborate seamlessly from any corner of the world, transcending limitations, language barriers, and physical boundaries. Crafting personalized virtual environments enables users to manifest their imaginative creations and seamlessly bridge the gap between the digital and tangible realms. Remarkably, the metaverse offers an inclusive space where individuals with diverse neurodiversity can explore without the constraints of the physical world, fostering learning and discovery in a more equitable environment [15]. This holds the potential to shape a more egalitarian reality.However, as the metaverse hosts both children and adults in an unregulated space (Figure 2), concerns arise about potential risks, particularly for tweens and adolescents vulnerable to exploitation and harm. To tackle these challenges, it becomes crucial to advocate for awareness, guidance, moderation, and enforcement within the metaverse. This necessitates the pivotal roles of parental guidance, adherence to PG-13 regulations, and collaborative efforts from non-governmental organizations (NGOs) to ensure a secure and safe metaverse experience.

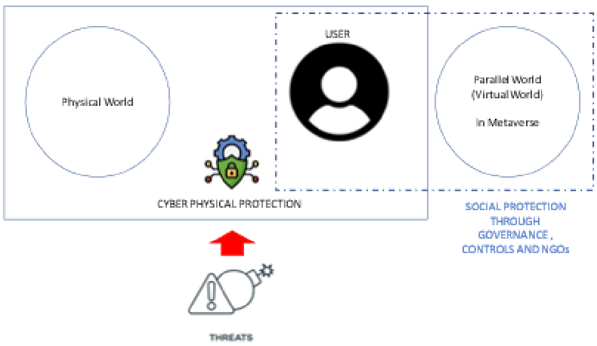

Figure 2: Cyber Physical + Social Protection Framework

The metaverse functions as a central point where the tangible and virtual realms converge, giving rise to a cosmos beyond reality. In order to seamlessly incorporate digital workspaces and learning environments, it is imperative to establish a crucial link between the virtual world and physical production systems. The

Industrial metaverse enables real-time physical interactions, enhances the visualization of Cyber-Physical Systems (CPSs), and serves as a digital replica of the workplace, thus elevating its overall functionality [16].Envision a virtual workplace, whether in two or three dimensions, that closely replicates its real-world counterpart, complete with standard amenities such as conference rooms, collaborative spaces, workstations, visual aids, and even communal areas for dining. Picture engaging in a virtual face-to-face meeting with colleagues who are represented by avatars, all from the comfort of your own home [17].

In a global pilot program carried out over a span of two months in 2022, forty employees from Cushman & Wakefield, hailing from five different countries, delved into the realm of virtual reality headgear. The outcomes were compelling, as ninety percent of new connections established in the metaverse translated into heightened cross-regional collaboration and client development. This organic collaboration fostered increased interaction among colleagues and the formation of new relationships. Employees encountered a unique form of spontaneous conversation, introductions, and connections, which were previously believed to be exclusive to in-person interactions, all thanks to the augmented reality dimension.Boeing's groundbreaking Mixed Reality (MR) application serves as a testament to the practical applications of the metaverse. This application provides trainees with step-by-step instructions, mixed reality visualizations, reference videos, and aircraft operation manuals, utilizing a virtual 3D replica of the aircraft and specialized aviation materials to facilitate Maintenance, Repair, and Overhaul (MRO) tasks [18].

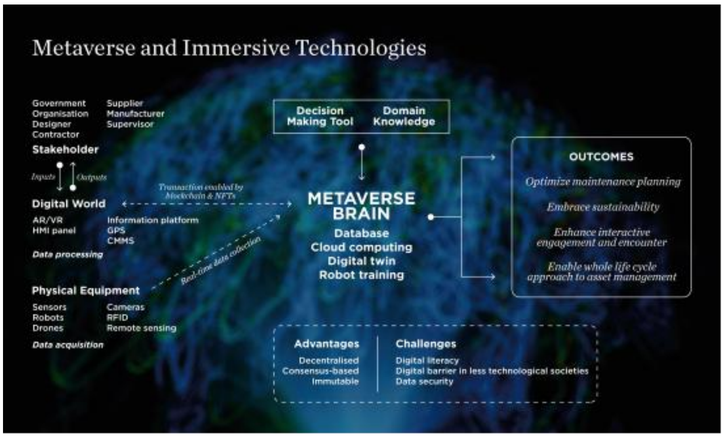

Figure 3: Metaverse Brain to improve operational efficiency and effectiveness.

Utilizing the technique of building information modeling, we possess the capability to produce a digital replica for a variety of projects, spanning from manufacturing facilities and data centers to entire smart cities. The engagement with this digital replica (as depicted in Figure 3) presents the opportunity to train automated machines within a simulated environment, thereby enhancing their performance in the real world. This strategy allows for a thorough examination and refinement of processes and operational procedures, all within a controlled setting, prior to their implementation in the physical realm.The convergence of the Metaverse and Immersive Technology harbors promising prospects for the real estate industry, ushering in a future where the virtual and real domains seamlessly align with objectives of sustainability. The rapid evolution of the digital landscape underscores our collective obligation as professionals in the building and estate industry to exploit these groundbreaking tools.The Built Environment sector, with its potential for transformation, can contribute to global betterment by seamlessly integrating sustainability and technology. The impact of the metaverse is reshaping how we construct and maintain global infrastructure. However, even the most robust plans lack significance without the involvement of stakeholders. Engaging stakeholders in the planning and design of the built environment allows for interventions and revisions prior to physical implementation. When combined with mixed reality, digital replicas, and virtual reality (as indicated in Figure 4), participatory urban planning empowers users to observe, provide feedback, and collaboratively modify the built environment before it assumes physical manifestation [19].

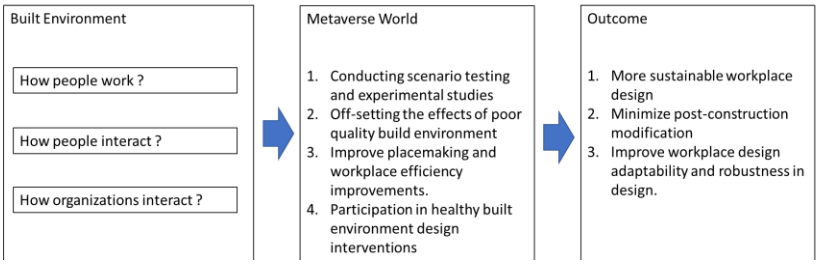

Figure 4: Metaverse in a Built Environment

Researchers possess the capacity to simulate intricate undertakings and predict future occurrences prior to their physical manifestation. In order to underscore the magnitude of a temperature rise surpassing 1.5°C, experiential learning via mixed reality enables students to comprehend the enduring ramifications of climate change in the forthcoming century.The constructed environment assumes a pivotal role in determining individual well-being, with "walkability" encompassing elements of urban design that foster pedestrian activity and other forms of physical exertion. The utilization of internet communication assists in expanding the knowledge of lawmakers and urban planners, guiding the development of built environments that optimize the integration of active modes of transportation and public transit [20, 21].As the metaverse grows increasingly intricate, the necessity for heightened data utilization arises. Data centers, integral components of the metaverse, pose a significant challenge due to their emissions of CO2. The optimization of energy consumption within data centers becomes imperative.Essentially, the substantial energy consumption of the metaverse mandates meticulous consideration of its environmental impact. Researchers and the technology sector bear the responsibility of learning from the metaverse's effects and ensuring that every technical decision prioritizes the well-being of the Earth.Applied mathematics presents opportunities to diminish the energy consumption of the metaverse. Innovative systems grounded in selective scanning, such as those devised by researchers at Nanyang Technological University in Singapore, streamline the creation of virtual realms by transmitting solely identified objects to metaverse service providers. Likewise, researchers at Shandong University employ advanced mathematical techniques to achieve a 40% reduction in measurement points while upholding precision in the establishment of digital replicas. This approach yields a metaverse with diminished carbon emissions, courtesy of swifter computation.Web 3.0 technology, with its decentralization through distributed ledgers and smart contracts, engenders sustainable outcomes. By eliminating intermediaries, manual intervention, and arbitration, this approach averts power consolidation and reduces costs, enabling businesses to acquire and distribute resources in a more prudent manner. Furthermore, digital transformation acts as a robust catalyst for environmentally responsible growth [22].Web 3.0 technology bolsters traceability and dependability through blockchain, ensuring the utmost level of control. The provision of secure, reliable, and safe smart contracts and transactions mitigates the risk of manipulation and corruption.

VI. IMPROVING MENTAL HEALTH AND WELLNESS IN WORKPLACES

The potential positive impact of the metaverse on psychological responses and behaviors in the real world relies heavily on its capacity to stimulate healthier habits within the virtual realm. The transformation of existing physical environments necessitates careful planning and substantial financial resources, as the presence of poorly designed, densely populated urban areas and congested transportation systems act as obstacles to the adoption of healthier lifestyles.Within the metaverse, individuals can seamlessly maintain their exercise routines within a virtual setting that is tailored to enhance their real-world surroundings. Taking inspiration from the Yerkes-Dodson law [23], the virtual workplaces within the metaverse offer employees the opportunity to achieve optimal levels of pleasant arousal, which may potentially enhance productivity. However, there is currently a lack of empirical research investigating the impact of exposure to a metaverse's health-promoting built environment on real-world health outcomes[24].The user-friendliness of devices that facilitate metaverse experiences requires improvement in order to address issues like motion sickness, thereby ensuring greater accessibility for learners. The creation of a digital representation that encompasses both avatars and the real world necessitates obtaining consent, as the potential replication of existing social structures within the metaverse raises questions about the digital divide.The protection of personal data, security, and privacy is of utmost importance for the metaverse, particularly in enabling students to navigate and engage in social interactions without concerns about identity theft or security risks. Additionally, it is crucial to consider the inclusivity of neurodiverse learners, addressing any potential barriers faced by vulnerable populations, including minorities and those with limited access, proficiency, or a sense of safety in metaverse engagement.Excessive time spent in the virtual world may supplant face-to-face interactions, resulting in social isolation, particularly among young people[26,27,28]. Furthermore, acute health issues such as headaches and eye strain are common in virtual environment[29]. The increasing popularity of the metaverse may potentially lead to a detachment from the real world, hindering active participation in decision-making processes related to urban planning or community health.Metaverses driven by artificial intelligence have the capability to replicate societal norms, which raises concerns regarding ageism, racism, and heteronormativity. Therefore, it is crucial to develop and disseminate guidelines that promote safe and healthful use of the metaverse in light of these considerations.The environmental impact of metaverse technologies, including significant carbon emissions and the potential for increased electronic waste, emphasizes the need for organizations to adopt a Safety by Design strategy. This strategy aims to identify and mitigate hazards at an early stage of technology development, while also taking into account the rights and safety of vulnerable groups, potential harms, and remedies associated with neurotechnology.Failure to adequately incorporate human rights concerns into the development of neurotechnology could disproportionately affect vulnerable groups, including individuals with neurodiverse conditions, various disorders, and children and young people. It is critical to consider how risks and remedies may differ in various circumstances, including those involving domestic violence, sexual violence, or family violence.

VII. CONCLUSION

The enduring and significant question is posed by the ongoing discourse surrounding the influence of the metaverse on real-world behavior.The true realization of the metaverse's potential lies in its ability to provide extensive access to experiential learning and training for the most disadvantaged populations, surpassing the limitations of time and space across geographic boundaries.However, marginalized communities may encounter obstacles when attempting to enter the metaverse. In order to establish an inclusive and equitable metaverse, it is essential to incorporate the principles of sustainability (represented by the 'S' in Metaverse ESG) from the outset, rather than retroactively implementing them after exponential expansion. The construction of a sustainable metaverse guarantees accessibility for all.A comprehensive and interdisciplinary examination of the metaverse's impact on resource optimization, well-being, and health remains crucial. In order to utilize the metaverse for evidence-based insights into the built environment and health, collaboration among engineers, researchers, and various disciplines such as information technology, artificial intelligence, software engineering, and computer engineering is indispensable. This collaborative endeavor will drive the metaverse towards advancing a knowledge base firmly rooted in the intersection of the built environment and health.

REFERENCE

[1]. Calm, Mystakidis, S. Metaverse. Encyclopedia 2022, 2, 486–497.
[2]. Dwivedi, Y.K.; Hughes, L.; Baabdullah, A.M.; Ribeiro-Navarrete, S.; Giannakis, M.; Al-Debei, M.M.; Dennehy, D.; Metri, B.; Buhalis, D.; Cheung, C.M.; et al. Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. Int. J. Inf. Manag. 2022, 66, 102542.
[3]. Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., et al., 2001.The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J. Expo. Anal. Environ. Epidemiol. 11, 231–252.
[4]. Locurcio LL. Dental education in the metaverse. Br Dent J 2022 Feb;232(4):191. [doi: 10.1038/s41415-022-3990-7]
[5]. Marteau TM, Hollands GJ, Fletcher PC. Changing human behavior to prevent disease: the importance of targeting automatic processes. Science 2012 Sep 21;337(6101):1492-1495. [doi: 0.1126/science.1226918] Gostin LO.
[6]. Walden, S., 2020. The "Indoor Generation" and the Health Risks of Spending More Time Inside.
[7]. Marmot AF, Eley J, Stafford M, Stansfeld SA, Warwick E, Marmot MG. Building health: an epidemiological study of "sick building syndrome" in the Whitehall II study. Occup Environ Med. 2006 Apr;63(4):283-9. doi: 10.1136/oem.2005.022889. PMID: 16556750; PMCID: PMC2078095.
[8]. Chokshi DA, Farley TA. Health. Changing behaviors to prevent noncommunicable diseases. Science 2014 Sep 12;345(6202):1243-1244. [doi: 10.1126/science.1259809] [Medline: 25214590]
[9]. FazeliDehkordi ZS, Khatami SM, Ranjbar E. The associations between urban form and major non-communicable diseases: A systematic review. J Urban Health 2022 Oct;99(5):941-958. [doi: 10.1007/s11524-022-00652-4] [Medline: 35776285]
[10]. L. Cao, "Decentralized AI: Edge Intelligence and Smart Blockchain, Metaverse, Web3, and DeSci," in IEEE Intelligent Systems, vol. 37, no. 3, pp. 6-19, 1 May-June 2022, doi: 10.1109/MIS.2022.3181504.
[11]. Hussain S (2023) Metaverse for education – Virtual or real? Front. Educ. 8:1177429. doi: 0.3389/feduc.2023.1177429
[12]. Florbela C. (2023) A Systematic Literature Review on Blockchain for Real Estate Transactions: Benefits, Challenges, Enablers, and Inhibitors, DOI: https://doi.org/10.21203/rs.3.rs-2823844/v1
[13]. Jules, Irabaruta,(2021), The use of blockchain in Real Estate.
[14]. Zheng, W., Yan, L., Zhang, W., Ouyang, L., & Wen, D. (2023). D-K-I: Data-Knowledge-Driven Group Intelligence Framework for Smart Service in Education Metaverse. IEEE Transactions on Systems, Man, and Cybernetics. Systems, 53(4), 2056–2061. https://doi.org/10.1109/TSMC.2022.3228849
[15]. Norris, N. G. (2023). How does my student learn? Neurodiversity and the nature of learning in autism. International Journal of Christianity & Education, 27(1), 65–87. https://doi.org.singaporetech.remotexs.co/10.1177/20569971221084350
[16]. Lee, J.; Kundu, P. Integrated cyber-physical systems and industrial metaverse for remote manufacturing. Manuf. Lett. 2022, 34, 12–15.
[17]. Cushman & Wakefield Edge Report , https://cushwake.cld.bz/The-Edge-Magazine-Vol-8/48/
[18]. Siyaev, A.; Jo, G.-S. Towards Aircraft Maintenance Metaverse Using Speech Interactions with Virtual Objects in Mixed Reality. Sensors 2021, 21, 2066. https://doi.org/10.3390/s21062066
[19]. Hudson- Smith A, Batty M. Ubiquitous geographic information in the emergent Metaverse. Trans GIS 2022 Apr 18;26(3):1147-1157. http://dx.doi.org/10.1111/tgis.12932

[20]. Westenhöfer, J., Nouri, E., Reschke, M.L. et al. Walkability and urban built environments—a systematic review of health impact assessments (HIA). BMC Public Health 23, 518 (2023). https://doi.org/10.1186/s12889-023-15394-4

[21]. Gan, Z., Yang, M., Zeng, Q., & Timmermans, H. J. P. (2021). Associations between built environment, perceived walkability/bikeability and metro transfer patterns. Transportation Research. Part A, Policy and Practice, 153, 171–187. https://doi.org/10.1016/j.tra.2021.09.007

[22]. Cao,W.; Cai, Z.; Yao, X.; Chen, L. Digital Transformation to Help Carbon Neutrality and Green Sustainable Development Based on the Metaverse. Sustainability 2023, 15, 7132. https://doi.org/10.3390/su15097132

[23]. Yerkes RM, Dodson JD. The relation of strength of stimulus to rapidity of habit-formation. J Comp Neurol Psychol 1908 Nov;18(5):459-482. [doi: 10.1002/cne.920180503]

[24]. Valdez VB, Javier SP. Digital divide: from a peripheral to a core issue for all SDGs. In: Filho WL, Azul AM, Brandli L, Salvia AL, Özuyar PG, Wall T, editors. Reduced Inequalities. Cham: Springer; 2020:1-14.

[25]. Abràmoff MD, Roehrenbeck C, Trujillo S, Goldstein J, Graves AS, Repka MX, et al. A reimbursement framework for artificial intelligence in healthcare. NPJ Digit Med 2022 Jun 09;5(1):72. [doi: 10.1038/s41746-022-00621-w] [Medline: 35681002]

[26]. Irie T, Shinkawa H, Tanaka M, Yokomitsu K. Online-gaming and mental health: loot boxes and in-game purchases are related to problematic online gaming and depression in adolescents. Curr Psychol 2022 May 07:1-12. [doi: 10.1007/s12144-022-03157-0]

[27]. 30. Smohai M, Urbán R, Griffiths MD, Király O, Mirnics Z, Vargha A, et al. Online and offline video game use in adolescents:measurement invariance and problem severity. Am J Drug Alcohol Abuse 2017 Jan;43(1):111-116. [doi: 10.1080/00952990.2016.1240798] [Medline: 27808562]

[28]. 31. Kowert R, Domahidi E, Festl R, Quandt T. Social gaming, lonely life? The impact of digital game play on adolescents' social circles. Comput Hum Behav 2014 Jul;36:385-390. [doi: 10.1016/j.chb.2014.04.003]

[29]. Park S, Lee G. Full-immersion virtual reality: adverse effects related to static balance. Neurosci Lett 2020 Aug 10;733:134974. [doi: 10.1016/j.neulet.2020.134974] [Medline: 32294492]