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Metaverse Sustainability: Driving energy efficiency and GHG emissions reduction

Working Group 8: Sustainability, Accessibility & Inclusion

Technical Report ITU FGMV-49

Metaverse Sustainability: Driving energy efficiency and GHG emissions reduction

Summary

This Technical Report explores the environmental impact of using metaverse applications and related devices. It offers guidance on how to make ICT devices and applications that support the operation of the metaverse more energy-efficient and sustainable. The goal is to reduce future greenhouse gas emissions.

In addition, the document examines the current and potential ways by which the metaverse fosters the green and low-carbon development of different economic sectors and industries.

The Technical Report recognizes the rapid development of digitalization, which has enabled and contributed to the growth of many sectors. The increasing use of the metaverse is deemed an additional tool empowering industries and impacting society and the economy. The document recognizes that among the horizontal priorities that need to be mainstreamed in metaverse development and usage is the environmental sustainability dimension, along with accessibility and inclusion.

This document addresses the environmental sustainability of the metaverse and related technologies for a smooth and energy-efficient development of the metaverse. To realize the full benefits of technological innovation, including metaverse usage, rapid technological development should be anchored in the ongoing efforts towards achieving the UN Sustainable Development Goals, including environmental impact mitigation.

Keywords

Energy saving; GHG emissions reduction; environmental sustainability; circularity

Note

This Technical Report is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Change Log

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Additional information and material relating to this report can be found at: https://www.itu.int/go/fgmv. If you would like to provide any additional information, please contact tsbfgmv@itu.int.

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Technical Report ITU FGMV-49

Metaverse Sustainability: Driving energy efficiency and GHG emissions reduction

1. Scope

This Technical Report aims to enhance the energy efficiency of the metaverse, thereby reducing greenhouse gas (GHG) emissions. Additionally, it provides guidance on improving environmental sustainability in various industries, such as tourism, education and manufacturing, through the use of metaverse technologies. The report covers several key areas:

- An analysis of the environmental costs and benefits of the metaverse, taking into account its current development and application scenarios.
- Exploring how the metaverse can contribute to environmental sustainability across different sectors and improve public perception of climate change and environmental issues.
- Providing evaluation method and roadmap for the green, low-carbon, and circular development of metaverse technologies and applications.

Through these insights and recommendations, the report aims to support the development of a more environmentally responsible metaverse ecosystem.

2. References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T P.1320] Recommendation ITU-T P.1320 (07/2022), *Quality of experience assessment of extended reality meetings*

[ITU-T X.1400] Recommendation ITU-T X.1400 (10/2020), *Terms and definitions for distributed ledger technology*

[ITU-T L.1410] Recommendation ITU-T L.1410 (12/2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*

[ITU-T L.1470] Recommendation ITU-T L.1470 (01/2020) Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement

[ITU-T L.1480] Recommendation ITU-T L.1480 (12/2012), *Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors*

[ITU-T Y.4000] Recommendation ITU-T Y.4000 (06/2012), *Overview of the Internet of things*

[ITU-T FGMV-01] Technical Report ITU-T FGMV-01(07/2023), *Exploring the metaverse: opportunities and challenges*

[ITU-T FGMV-08] Technical Report ITU-T FGMV-08(10/2023), *Design criteria and technical requirements for sustainable metaverse ecosystems*

[ITU-T FGMV-20] Technical Specification ITU-T FGMV-20 (12/2023), *Definition of metaverse*

[ITU-T FGMV-27] Technical Report ITU-T FGMV-27 (03/2024), *Guidelines of metaverse application in power system*

[ISO/IEC 18039:2019] *Information technology- Computer graphics, image processing and environmental data representation- Mixed and augmented reality (MAR) reference model*

3. Definitions

3.1 Terms defined elsewhere

This set of Technical Specifications uses the following terms defined elsewhere:

3.1.1 Metaverse [ITU-T FGMV-20]: An integrative ecosystem of virtual worlds offering immersive experiences to users, that modify pre-existing and create new value from economic, environmental, social and cultural perspectives.

NOTE- A metaverse can be virtual, augmented, representative of, or associated with the physical world.

3.1.2 VR [ITU-T P.1320]: An environment that is fully generated by digital means. To qualify as virtual reality, the virtual environment should differ from the local environment.

3.1.3 AR [ITU-T P.1320]: An environment containing both real and virtual sensory components. The augmented reality continuum runs from virtual content that is clearly overlaid on a real environment (assisted reality) to virtual content that is seamlessly integrated and interacts with a real environment (mixed reality).

3.1.4 MR [ITU-T P.1320]: An environment containing both real and virtual components that are seamlessly integrated and interact with each other in a natural way (one end of the augmented reality continuum).

3.1.5 Greenhouse gases (GHGs) [ITU-T L.1410]: For the purposes of this methodology, GHGs are the seven gases listed in the Kyoto Protocol:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- hydrofluorocarbons (HFCs)
- perfluorocarbons (PFCs)
- sulphur hexafluoride (SF_6)
- nitrogen trifluoride (NF_3).

3.1.6 NFT [ITU-T X.1400]: An entirely unique digital representation of an asset.

3.1.7 Virtual world [ISO/IEC 18039:2019]: Virtual environment, spatial organization of multiple virtual objects, potentially including global behaviour.

3.1.8 IoT [ITU-T Y.4000]**:** A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) thins based on existing and evolving interoperable information and communication technologies.

3.1.9 First order effect [ITU-T L.1480]: Direct environmental effect associated with the physical existence of an ICT solution, i.e., the raw materials acquisition, production, use and end-of-life treatment stages, and generic processes supporting those including the use of energy and transportation.

NOTE 1 – First order effects include GHG and other emissions, e-waste, use of hazardous substances and use of scarce, non-renewable resources.

NOTE 2 – First order effects are sometimes referred to as environmental footprints.

NOTE 3 – This definition has been amended from [ITU-T L.1410].

3.1.10 Second order effect [ITU-T L.1480]: The indirect impact created by the use and application of ICTs which includes changes of environmental load due to the use of ICTs that could be positive or negative.

3.1.11 Net second order effect [ITU-T L.1480]: The resulting second order effect after accounting for emissions due to the first order effects of an ICT solution.

3.1.12 Higher order effect [ITU-T L.1480]: The indirect effect (including rebound effects) other than first and second effects occurring through changes in consumption patterns, lifestyles and value systems.

3.1.13 Rebound effect [ITU-T L.1480]: Increases in consumption due to environmental efficiency interventions that can occur through a price reduction or other mechanism including behavioural responses (i.e., an efficient product being cheaper or in other ways more convenient and hence being consumed to a greater extent).

3.1.14 Circularity [ITU-T L.1070 (11/2023)]: Designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

3.2 Terms defined in this Technical Report

This set of Technical Specifications defines the following terms:

3.2.1 Environmental sustainability: Responsibility to conserve natural resources and protect the global ecosystems including earth well-being and individual's health and wellbeing now and in the future.

4. Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC Alternative current

AI Artificial intelligence

AR Augmented Reality

DC Direct current

DeFi Decentralized Finance

GHGs Greenhouse Gases

HMD Head-mounted display

ICT Information communication technology

IoT Internet of things

IPFS InterPlanetary File System

MR Mixed Reality

NFT Non-fungible token

PCF Product carbon footprint

ROI Return on investment

SDGs Sustainable development goals

VR Virtual Reality

5. Conventions

None.

6. Embracing environmental sustainability in the metaverse

Embracing environmental sustainability in the metaverse involves integrating eco-friendly practices into developing and operating virtual environments and related technologies. This includes minimizing energy consumption, reducing carbon emissions, and promoting sustainable resource use. The metaverse can play a positive role in addressing global challenges such as climate change. Collaboration among developers, users, and policymakers is essential to ensure that the metaverse evolves in a way that is both innovative and environmentally responsible.

The international community is striving to achieve the Sustainable Development Goals (SDGs) before 2030; The application of the metaverse may help reach sustainable development in the future, especially for SDGs 4 Quality Education, 8 Decent Work and Economic Growth and 11 Sustainable Cities and Communities.

In terms of metaverse applications, it is noticeable that many physical activities, including travelling, trading and shopping etc., can be substituted, complemented or improved through the virtual world [b-E&Y], hence creating remarkable changes in the operation of many economic sectors/ industries in society.

Experts and researchers argue that substituting physical activities with metaverse technologies and applications such as digital twin and immersive experiences could bring sustainability benefits because much less energy consumption and greenhouse gas (GHG) emissions are emitted compared with the same physical activities in the real world. Digital twins, for instance, can potentially optimize the physical world with less environmental cost.

With the spreading out of renewable energy utilities, scientific research found a more suitable way to reduce GHG emissions, but with higher energy requirements. This kind of green energy (e.g. solar, wind, biomass, etc.) is much more prevalent in supporting the worldwide energy transformation. One issue to be considered is how to construct the infrastructure of renewable energy and how to use solar, wind and other energy in a more significant percentage of the total energy system. Metaverse technologies can provide a solution by offering applications of digital twin to optimize the use of renewable energies.

On the other hand, the rebound effects associated with the future rapid development of metaverse applications cannot be ignored. The energy consumption and GHG emissions have come to the fore as compute-intensive transactions skyrocket. For example, there is a chasm between the energy use and carbon costs of the relatively few participating in cryptocurrency transactions and the rest of the world. [b-rebound]

It is important to point out that the large-scale application of the metaverse will lead to the use of large quantities of information communication technology (ICT) devices. It will also trigger the development and production of new kinds of devices (supporting the different metaverse platforms). The increasing consumption of devices and production of new devices is expected to increase energy consumption.

7. Global Net Zero targets and the metaverse

Net Zero means cutting net greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, for instance by oceans and forests. Scientific studies show that in order to avert the worst impacts of climate change and preserve a liveable planet, global temperature increase needs to be limited to 1.5°C above pre-industrial levels. The Earth is already about 1.1°C warmer than it was in the late 1800s, and emissions continue to rise [b-Paris Agreement]. To keep global warming no more than 1.5°C – as called for in the Paris

Agreement, GHG emissions need to be reduced by 45 per cent by 2030, and reach Net Zero by 2050. [b-Paris Agreement]

Transitioning to a Net Zero world is one of humankind's most significant challenges. It calls for nothing less than a complete transformation of how we produce, consume, and move about. The metaverse can contribute to this transition.

ITU-T, in collaboration with GSMA GeSI and SBTi published [ITU-T L.1470] an international standard defining the trajectory of emissions for ICT based on the Paris Agreement. Metaverse devices/ technologies, as part of ICT applications, should consider this trajectory and respect it.

8. Enhancing the environmental sustainability of the metaverse

The metaverse is realized by a series of advanced ICT technologies, including big data, cloud computing, blockchain, artificial intelligence (AI) and Internet of Things (IoT). Regarding environmental sustainability, the infrastructure supporting the operation of the metaverse may produce much power consumption and GHG emissions, with more e-waste. Therefore, it is necessary to identify and measure the environmental impact of the metaverse applications by themselves and activities realized throughout the operation from the base station site (for networks and connectivity), data centre (for computing, storage), and mobile terminal (for sensing or perception).

How can society and the economy benefit from the energy savings offered by the metaverse in different sectors while mitigating its potential environmental cost? This paradox is addressed below.

8.1 Key technical requirements and infrastructure for the environmental sustainability of the metaverse

The report notes the technical requirements for energy efficiency and environmental aspects for data design and management, virtual environment generation, avatar characterization and interaction, object regeneration, and recognition and rendering, Infrastructure and devices, as outlined in table 3-7 of the technical report [ITU-T FGMV-08] entitled Design criteria and technical requirements for sustainable metaverse ecosystems.

To complement this listing and to enhance the environmental sustainability of the metaverse, it is imperative to address the infrastructure, which is the foundational layer to meet the technical requirements on energy efficiency and environmental aspects, including the following elements:

8.1.1 Communication and networking infrastructures

Efficient IMT 2030/5G and beyond, other mobile platforms and fixed network access and transport are essential due to rising data generation and consumption trends, particularly for user-end metaverse applications. ITU-T standards highly relevant to the sustainability of metaverse network infrastructure include Recommendation ITU-T L.1310 “Energy efficiency metrics and measurement methods for telecommunication equipment”. On the other hand, ITU-T L.1331 “Assessment of mobile network energy efficiency” provides the requirements and determines the KPI for the efficiency of ICT equipment and mobile network. ITU-T L.1333 “Carbon data intensity for network energy performance monitoring” defines a KPI for the carbon emission of all types of networks. The application of these standards and their requirements are essential to developing environmentally sound and sustainable networks used in the metaverse.

8.1.2 IT infrastructures

Cloud services, third-party services, and data centres require intent-driven orchestration, emphasizing energy efficiency. These orchestrations span across IoT, edge, and cloud resources. Integrating IoT, edge, and cloud tech is vital for a smooth transition to metaverse-centric systems.

8.1.3 ICT devices: Sensors and actuators (e.g, HMDs)

- Head-mounted devices (HMDs): Track head movements, offering varied perspectives in the virtual world. Types include non-see-through, optical-see-through, and video-see-through HMDs. Typically, they are bulky, pricey, and have limited battery duration.
- Hand-based and non-hand-based devices: Utilize physical space or gravity senses, body tracking, and treadmills for precise motion capture.
- Motion input devices: Utilize physical space or gravity senses, body tracking, and treadmills for precise motion capture. [b-ITU-T FGMV-01]

8.2 Suggested approaches to mitigating the carbon emissions of the metaverse

Based on the mentioned technologies and infrastructures in section 8.1, which support the application of the metaverse, it is possible to assert that computational ability and networking are the most important physical parts supporting the operation of the metaverse from the perspective of the real world. The metaverse draws far more electricity than previous online technologies [b-ITU-T FGMV-01]. Hence, it will increase data centre and telecom site activities and corresponding GHG emissions. Moreover, the portable and terminal devices are also the main parts that help accomplish the immersive experience for humans, so they will draw on some energy to power these devices, and the resulting GHG emissions might be produced. It is also important to note that continuous technology development can create an influx of e-waste.

To mitigate the GHG emission of the metaverse technologies, the following actions are recommended:

8.2.1 Increase the proportion of renewable energy use

Focusing on the external energy supply of new infrastructure, green power line supply technology is needed. Given the self-generation and self-consumption of green energy in new infrastructure, it is a must to coordinate the site selection, design, operation, maintenance and other aspects of green self-built power stations. Based on the level of green energy consumption, it is necessary to focus on new infrastructure such as green data centres [ITU-T L.1300], low carbon 5G base stations [b-5G base station] and green industrial Internet [b-green industrial], covering indicators such as the proportion of green electricity utilization and the level of energy recycling, so, as to promote GHG emission reduction and sustainable development at the source of new infrastructure.

8.2.2 Apply energy-saving and GHG-emission-reduction technologies

Promoting the application of energy-saving technologies such as natural cooling sources, liquid cooling, and proximal refrigeration in data centres, accelerate the application of GHG-emissions-reducing technologies such as channel immersion of communication base stations and energy-saving control of air conditioners, and strengthen the supply capacity of traditional computer rooms to improve energy efficiency and green transformation standards. In addition, this report recommends promoting the evaluation of the GHG emissions reduction effect of converged infrastructure such as the Internet of Vehicles and the Industrial Internet on traditional industries, form digital GHG emissions reduction index requirements and evaluation methods, and promote the coordinated development of digital and green convergence infrastructure.

8.2.3 Promote recyclability, resource efficiency and proportionality

Promote the recycling of information infrastructure resources, focus on the waste heat recovery of data centres, methods for extending the service life of base station main equipment, and transformation and reuse of old computer rooms, and carry out related applications. For the convergence of infrastructure, accelerate the recycling of resources, the comprehensive utilization of industrial solid waste, and the recycling of waste power batteries. Improve standards for the co-construction and sharing of resources such as pipelines, poles, optical cables, and computer rooms, and accelerate the pilot demonstration applications related to the co-construction and sharing of information infrastructure and social resources such as transportation, electric power, and smart light poles.

The existing circularity standards on assessment and adoption can be applied to metaverse devices to ensure their sustainability throughout their life cycle, especially when they become obsolete. They include Recommendations ITU-T L.1020 “Circular economy: Guide for operators and suppliers on approaches to migrate towards circular ICT goods and networks”; ITU-T L.1023 “Assessment method for circularity performance scoring”; and ITU-T L.1070 “Global digital sustainable product passport opportunities to achieve a circular economy”.

8.2.4 Promote energy efficiency of ICT products

For information infrastructure, it is recommended to create standard capabilities in terms of energy efficiency classification and energy consumption quotas. For core products used for computing, storage, and network communication, it is important to consider increasing energy efficiency per unit of business. This supports products such as power supply, temperature control and energy storage. It is also important to focus on the R&D and application of related products such as energy conversion efficiency improvement and multi-energy regulation and control. For converged infrastructure and products with high intelligence, such as energy IoT devices and energy routers, relevant research should be carried out on energy consumption and energy efficiency improvement.

8.2.5 Establish a management platform for GHG emissions accounting and smart energy solutions

It is recommended to adopt the agreed-upon methodologies on environmental impact assessment of ICT devices, networks and services, and even ICT organizations, which are reflected in the following standards: Recommendations ITU-T L.1410 “Methodology for environmental life cycle assessments of information and communication technology goods, networks and services” and ITU-T L.1420 “Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations”. It is possible to establish a digital platform to accurately monitor the GHG emissions from product carbon footprint (PCF), data centres, base station sites, telecommunication rooms, and so on., to figure out what can be optimized in terms of GHG emissions reduction and what the effect of some strategies and actions given by smart technology on energy-saving and GHG emissions reduction are.

8.3 How the metaverse can influence human behaviour towards climate change mitigation

Different studies show that behaviour is one of the most significant barriers to addressing climate change. The short-term return on investment (ROI) are much more attractive to people than long-term targets such as climate change mitigation. The changes in human behaviour needed for adopting proactive steps towards climate change mitigation are not eminent because of the absence of foreseeing thinking and experience [b-E&Y]. If behaviour is the most significant barrier to addressing climate change, immersive experiences can amplify emotional engagement with the issue and drive meaningful action.

The immersive experiences, which form a central element of the metaverse, have the ability to tap into other parts of the human psyche to create new climate consciousness that could spur action. The VR environment provides users with three key dimensions of experience:

- Presence: users forget they are in a synthetic, mediated experience.
- Immersion: the technological quality of the medium enables presence.
- Embodiment: one can believably change perspective or character in the environment.

Experiments related to VR and climate and other sustainability issues have shown that immersive experiences yield better learning outcomes, more personalized impact, and greater emotional engagement with the issue. Similar embodiment experiences - as a climate migrant or someone impacted by an extreme weather event- could have the potential to drive meaningful climate action.

9. Metaverse applications supporting environmental sustainability

In contrast to the problem of power consumption and GHG emissions of metaverse technologies and infrastructure presented in section 8, the metaverse has the potential to contribute to greening and reducing GHG emissions in our societies. With the maturity of the metaverse, people will gradually realize the easy transfer of the physical world to the virtual world. They can participate in various activities in the virtual space, such as business meetings and travel, in order to reduce the energy consumption and friction caused by human activities in the physical world, thereby effectively reducing GHG emissions.

Metaverse applications offer different enablement scenarios and can realize different functions based on the properties of each sector they serve. The following section provides case examples from various industries and how the metaverse can play a role in the environmental sustainability of these sectors. In addition, Appendix A offers more detailed case studies.

It is recommended, when using metaverse technologies in different sectors, to consider their impact and how to assess it (See Recommendation ITU-T L.1410). A detailed assessment of the environmental effect of metaverse technologies can be done with the help of Recommendation ITU-T L.1480 "Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors", especially in what concerns the net second order effect of ICT including the metaverse technologies see figure 1. A detailed description of the assessment of the metaverse is provided in section 10.

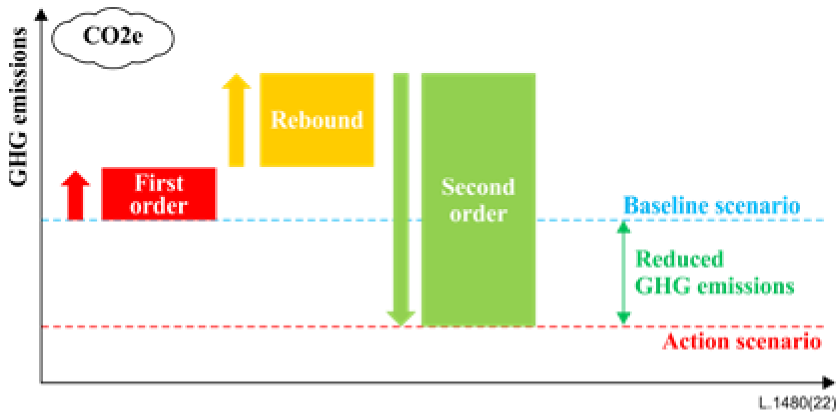

Figure 1 Enablement effect by ICT on other sectors [b-ITU-T L.1480]

9.1 The metaverse and environmentally sustainable real-estate

In the realm of environmentally sustainable real estate, the integration of metaverse technologies presents a paradigmatic shift, offering advanced solutions across various industry sectors, encompassing property management, investment, valuation, and more. Real estate is inherently complex, comprising numerous business components such as property tours, transactions, management, and valuation. However, the application of metaverse technologies revolutionizes this landscape, enabling the majority of processes to be conducted within virtual environments.

Consider a scenario where prospective buyers or tenants can engage in virtual property tours from the comfort of their own homes, leveraging immersive metaverse platforms. This optimizes resource utilization and drastically reduces GHG emissions associated with traditional property viewings, ushering in a new era of eco-conscious property exploration.

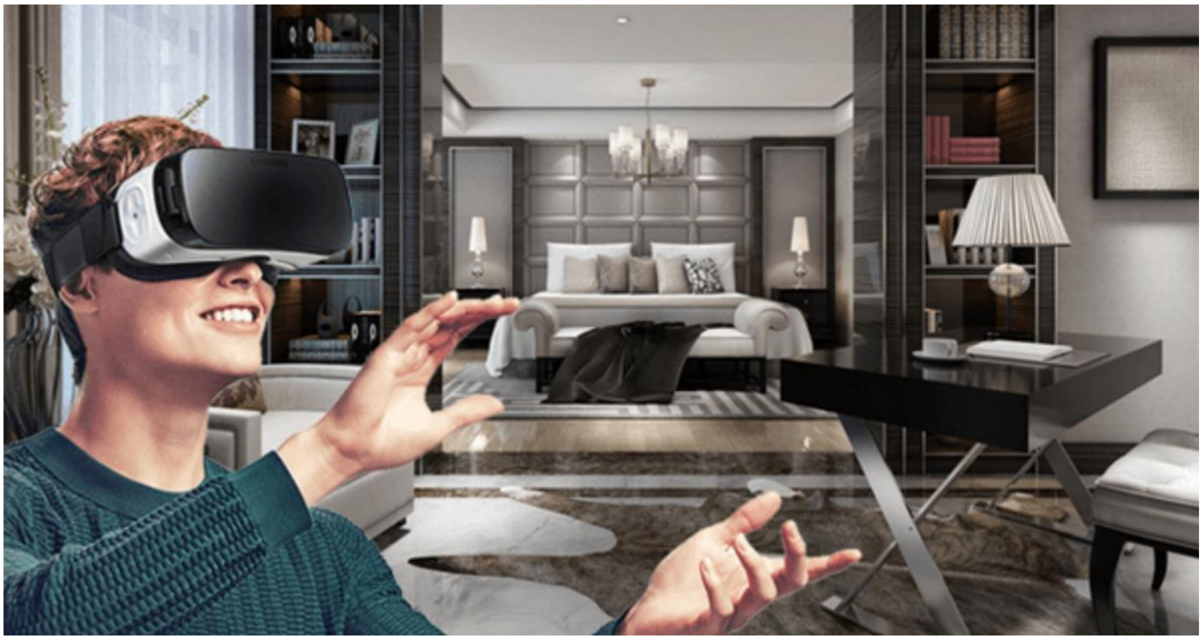

Figure 2 - Virtual room tour [b-DigitalWorld]

Moreover, metaverse technologies streamline transactional processes, introducing seamless property sales and rentals through digitized documentation and remote transactions. This digital transformation minimizes reliance on paper-based workflows, significantly reducing resource consumption and environmental impact.

Furthermore, metaverse platforms within property management leverage smart sensors and IoT devices to monitor and regulate energy usage within real estate properties. Real-time data analytics enable precise adjustments to heating, cooling, and lighting systems based on occupancy patterns and environmental conditions, resulting in substantial energy savings and reduced greenhouse gas emissions.

In the domain of urban planning and development, the metaverse emerges as a powerful tool for visualizing and assessing the environmental impact of proposed real estate projects. Virtual simulation (which is the partial immersion through a digital environment; e.g., computer, tablet, phone, screen, etc., to foster a perceived lived experience for an intended outcome; and the use of 3D objects and environments to create immersive and engaging learning experiences [b- virtual simulation] and urban modelling facilitate a comprehensive analysis of factors such as building orientation, green space allocation, and infrastructure design, empowering stakeholders to make informed decisions that prioritize sustainability and mitigate potential environmental risks.

In summary, the integration of metaverse technologies in the real estate sector represents a significant step towards advancing environmental sustainability. The metaverse fosters the creation of eco-friendly, resilient built environments by harnessing virtual experiences, optimizing processes, and enabling data-driven decision-making. As the industry continues its digital transformation journey, leveraging the technical capabilities of the metaverse holds the key to building greener, more sustainable communities for future generations. [b-Aston Group]

9.2 The metaverse and environmentally sustainable manufacturing

The metaverse can contribute to sustainable manufacturing at different stages:

- In safety training; safety monitoring; process simulation; auxiliary assembly; product testing.

By using industrial simulation software and wearable intelligent devices as the main tool carriers, manufacturing transparency is achieved in certain stages such as design, production, operation, maintenance and services, thus improving production efficiency and accuracy while consuming less energy and more effective resource utilization.

- At the planning stage, manufacturing by the metaverse offers a full scene virtual simulation to realize the virtual reality interactive mapping of key scene modules. In complex manufacturing and global supply chains, the industrial metaverse can break down communication disorders such as geographical, language and time differences, significantly improve industrial collaboration efficiency, and improve supply chain flexibility and linkage capability. Thus, the process positively impacts resource usage and leads to less waste generation.

- The virtual industrial park breaks through the limitation of land space. It uses digital and intelligent technology to connect related industrial enterprises scattered all over the country to form an industrial ecology. The virtual park dissolves the boundary of the physical space, greatly exerts the cluster effect, and also expands the online social scene and virtual consumption format.

- The metaverse provides a rehearsal platform for technological innovation. Digital twins, cloud computing and digital technologies provide researchers with a flexible, efficient and pollution-free virtual experimental site. All kinds of low-carbon technology testing and analysis can be simulated in this virtual laboratory, which is convenient for researchers to explore flexibly, the overall impact of a single variable or parameter on the experimental results, verify the feasibility of technology implementation, greatly shorten the low-carbon technology research and development cycle, reduce the cost of research and development and trial and error, reduce the energy loss in the research and development process, and provide strong support for low-carbon technology innovation.

Figure 3 Manufacturing with digital twin [b-DigitalTwin]

9.3 The metaverse and environmentally sustainable education and work

9.3.1 Education in the Lab with the metaverse

Through the use of remote immersive experiences, the function and participation of the virtual classroom have been greatly improved, and the productivity of education has increased significantly. From the perspective of the purchasing and usage of the devices, the metaverse can reduce this kind of cost and power consumption on a large scale. In scientific research and education, metaverse technology can simulate expensive teaching equipment, restore mechanical equipment, and assist teachers in teaching. When applied to human anatomy, surgical simulation, chemical experiments and other fields, it reduces the loss of experiments significantly. It can also play a role in protecting the safety of teachers and students in experiments with higher-risk probability.

Figure 4 Virtual experiment in college [b-Oubeier]

An example of a use case in education is the Educational Virtual Environment (EVE) Lab at the American University in Cairo, which offers students the opportunity to engage with emerging technologies and explore the digital future. The Lab provides students with a unique opportunity to engage with emerging technologies and gain practical experience in their respective fields. By using virtual reality, students can visualize complex concepts, detect design flaws, improve their problem-solving skills, experience the metaverse first hand and explore its potential applications. Faculty members can use the immersive nature of virtual environments to enhance their teaching methods and provide a better understanding and visualization of architectural space and form. The Lab's facilities enable professors to delve into aspects of scale, proportion, spatial experience, design development, and details that would have been challenging to represent.

This solution allows students to have this experience without the need to travel to a remote site, so reducing the environmental cost of the experience.

9.3.2 Remote work with the metaverse

By utilizing metaverse applications, people can work remotely through different types of technologies without leaving home. In addition, they can also extend this experience by sharing offices with colleagues in the online space. With the help of their avatars and virtual identities, people can accurately convey movements, expressions and tones of the characters in the real space and enjoy a more realistic office experience.

In comparison to real space, the most prominent feature of the metaverse is that it is virtual, and the scene layout, conference organization, conference and exhibition and other all-virtual work of virtual exhibitions provide more choices for people's employment in the future.

With the development of future network technologies such as IMT- 2020/5G and beyond, the network connection speed of meetings in the metaverse will be significantly improved, ensuring a smooth virtual experience. The rise of smart glasses will also allow attendees to interact with the virtual world more naturally.

This leads to a reduction in the energy consumption from daily commuting by bus, train and car, and also a reduction of power consumption from, for example, office buildings, etc. GHG emissions, especially from fossil fuels generated by the transportation system, are largely reduced.

Figure 5 Virtual meeting in metaverse [b-CoG]

9.4 The metaverse and environmentally sustainable travel

Air and ground, recreational and business travel could also be replaced significantly by metaverse experiences. Air travel accounted for 2.5 per cent of global emissions prior to the onset of the COVID-19 pandemic, after which the sector's emissions were cut in half. [b-WWF]

Considering that tourism is one of the highest GHG emissions industries globally, the digital twin technology of the metaverse can accurately mirror the natural and cultural landscapes in the virtual world. Thus, people can get a multi-sensory linkage immersive experience of face-to-face conversations in various places and other scenarios without leaving home, reducing the frequency of use of different transportation means, thereby reducing GHG emissions in the transportation industry. [b-courier]

Figure 6 Virtual traveling [b-Metaverse for travel]

9.5 The metaverse and environmentally sustainable retail

As metaverse offerings become increasingly more compelling, consumers might shift the allocation of their limited budgets to more sustainable virtual options, yielding significant positive and environmental sustainability impacts.

Embodied in the global denim trade, for example, are 16.0 Mt CO_2e and 4.7 billion m^3 of water annually. The carbon reduction and water savings could be substantial if consumers opted to buy virtual denim for their avatars instead of real denim for their physical bodies. Already, 21 per cent of consumers intend to buy fewer physical items in the future because they expect to do more things digitally. [b-E&Y]

If this kind of substitution reduced the physical denim trade by 10 per cent, it would reduce CO_2 emissions by the equivalent of the annual emissions of nearly 350000 American internal combustion automobiles, and water consumption by the equivalent of the annual average per capita footprint of more than 400000 Chinese consumers. Taken across the various categories of consumer spending, substitution effects could result in substantial carbon and resource efficiencies [b-E&Y]

A lifelike virtualization of the experience of trying on clothes could also yield meaningful sustainability benefits. As online sales have increased globally, so have returns. In the US, for example, 21 per cent of online sales were returned in 2021. The returns result in doubling the transportation miles with packaging and stocking. Companies sometimes overproduce items in response to these false signals, leading to more waste. [b-E&Y Future Consumer Index]

Figure 7 Virtual retailing [b-retailing in metaverse]

9.6 The metaverse and environmentally sustainable energy

The general characteristics of the energy industry include heavy assets, heavy equipment, heavy operation, safe production, etc., and basic energy substances, which also have financial attributes. One of the energy industry's essential goals is improving asset utilization, production and operation efficiency, safety production level, and energy consumption. For future development of the energy industry, higher proportionality on renewable energy and higher generating efficiency on fossil fuels should be considered to make it much more sustainable for the environment.

Metaverse applications can optimize the industrial structure by solving the problem of new energy development and promoting the low-carbon transformation of traditional enterprises. On the one hand, renewable energy applications face issues such as difficulties matching supply and demand and unstable output. At the same time, digital technology can run through the whole chain process of new energy from production to management, intelligently control the stable operation and close cooperation of all links, and efficiently match the supply and demand of resources, bringing opportunities for the development of new energy. On the other hand, with the empowerment of digital technology, substantial progress has been made in the construction of a carbon emission monitoring system, and various energy industries can easily realize real-time monitoring of carbon emission levels in the production process, obtain comprehensive and accurate measurement data and excess carbon emission feedback, and make timely production management adjustments to accelerate the transformation of low-carbon industries. [b-energy]

In the energy industry, historical data can be mined to obtain effective and potentially valuable information from a large amount of business data through the digital twin-related technology of the metaverse. The typical application scenario in energy metaverse is in the power industry, as per The Technical Specifications entitled "Guidelines of metaverse application in power system" [ITU-T FGMV-27], including virtual power plant, smart grid management, and power trading.

The metaverse technologies contribute to the following, which could lead to energy efficiency and, hence, environmental sustainability:

- Discover potential energy resources through 3D modelling and digital twins, make decisions based on expert experience, and provide remote support for expert work. Through 3D visualization technology, combined with XR terminals, operators can have 3D visual control of the complete energy manufacturing process based on a user-friendly interactive interface, while ensuring that remote experts can communicate and interact with the site to guide, optimize and assist in decision-making.
- Digital twin and virtual space technologies are particularly suitable for solving the production safety problems faced by the energy industry in the upstream energy acquisition stage, such as field mining and offshore exploration.

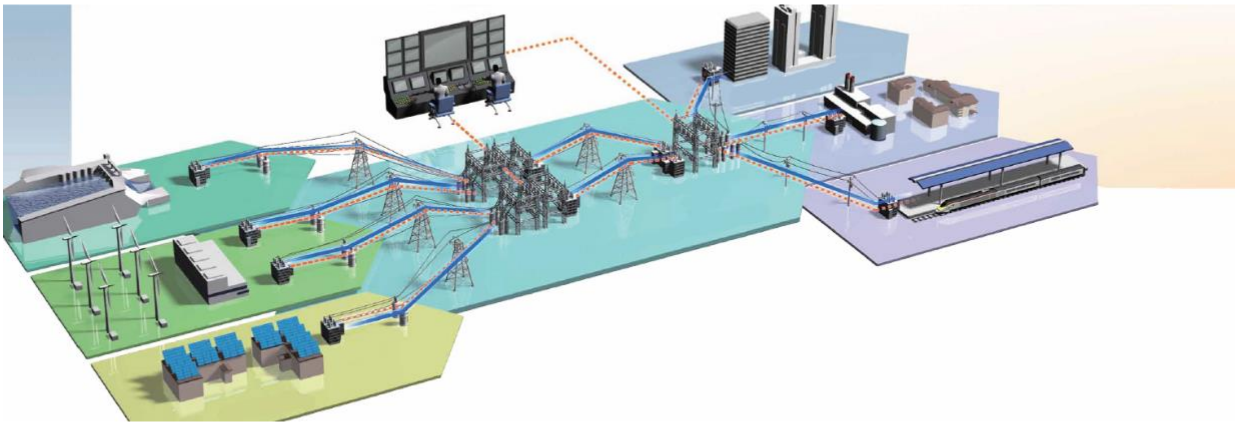

Figure 8 Virtual power system [b-PowerMetaverse]

10 Evaluation of metaverse effect on industry and other business sector

Metaverse technologies, though their physical existence, have environmental impacts at each stage of their lifecycles (first order effects), which need decarbonization. They can also enable vast efficiencies in lifestyle and in all sectors of the economy through the provision of solutions that can improve energy efficiency, inventory management and business efficiency by reducing travel and transportation, and by substituting digital information for physical products (positive second order effects). At the same time, the metaverse can be employed in uses that serve to maintain or even increase the fossil-based economy (negative second order effects), resulting in higher GHG emissions. Additionally, effects enabled by the use of metaverse solutions can be modified due to rebound, i.e., the tendency that increased efficiency is offset by increases in emissions due, for example, to consumption. Moreover, the metaverse can have significant effects at the societal level by reshaping how people live their lives. (These two effects are referred to jointly as higher order effects, and can be positive or negative.) [b-ITU-T L.1480]

Detailed discussion and methodology on how to assess this effect is available in [b-ITU-T L.1480]; for a description of what is considered a first and second effect, as well as a discussion on other effects such as rebound, see [b-ITU-T L.1480] Appendix II.

10.1 First order effects of the metaverse

For the application of the metaverse, ICT goods, networks, and services are the basis associated with the environmental load emerging from different processes over the life cycle. The environmental impact caused by this environmental load is sometimes referred to as first order effects.

As ICT networks are composed of ICT goods and as ICT services utilize ICT networks, the methodology for the environmental life cycle assessments for ICT goods is the basis for the methodologies for ICT networks and ICT services. In other words, the methodology for ICT networks is based on the methodology for ICT goods, and the methodology for ICT services accommodates both methodologies for ICT goods and networks. Consequently, the environmental impact assessment of ICT networks reflects the environmental impact of ICT goods employed in the ICT networks, and the environmental impact assessment of ICT services reflects the environmental impact assessments of ICT goods and ICT networks employed in the ICT services. [ITU-T L.1410]

ICT networks and ICT services can be seen as logical structures, which are physically made up of ICT goods, including hardware and software, but which also rely, for instance, on building premises, civil works to create cableways, air conditioning, power generators and power storage such as an uninterruptible power supply (UPS).

The first order effects of the metaverse should consider the various goods used, for example:

- End-user goods
- Customer premises equipment
- Access network
- Control and Core network
- Operator activities
- Data transport
- Data centre(s)
- Service provider activities

Moreover, the eight checklist items may be considered per functional unit to identify the life cycle processes contributing to the overall first order effect. In this case, [ITU-T L.1410] indicates:

• The following eight checklist items should be considered in the system boundary setting of ICT services, including their associated goods and networks, to identify activities associated with their life cycle and usage".

• "The intention of the eight checklist items above is to ensure that all relevant impacts are considered for all life cycle stages when defining the impact from a product system viewpoint. These are typical items to be often considered, but other items may be considered as well depending on study."

Thus, the eight checklist items to consider are:

- ICT hardware
- ICT software
- Consumables and other supportive products
- Site infrastructure
- Transport (movement of goods)
- Travel (movement of people)
- Storage of goods
- Working environment. [ITU-T L.1480]

10.2 Second order effects of the metaverse

The six categories and the related potential corresponding second order effects are:

- Consumption of goods (e.g., paper, CDs, DVDs): by reducing the consumption of goods (e.g., paper), the environmental impact related to goods can be reduced.
- Power consumption/energy consumption (e.g., electricity, gasoline, kerosene, light oil, heavy oil, town gas): by enhancing the efficiency of power and energy use, the environmental impact related to power can be reduced.
- Movement of people (e.g., car, bus, railroad, aircraft): by reducing the movement of people, the environmental impact required for travel can be reduced.
- Movement and storage of goods (e.g., mail, truck, railroad cargo, air cargo, cargo ship): by reducing the movement of goods, the environmental impact required for transportation and storage can be reduced.
- Improved work efficiency (e.g., electricity, office area): by using office space efficiently, power consumption for lighting, air conditioning, and so on, can be reduced, thus reducing the environmental impact.
- Waste (e.g., wastepaper, garbage, plastic, industrial waste): by reducing waste emissions, the environmental impact for waste disposal, etc. can be reduced.

In the same way with section 10.1, these six comparison items may be used as a starting point for ensuring that most of the relevant impacts of the second order effects are considered:

- Consumption of goods
- Power consumption/energy consumption
- Movement of people
- Movement and storage of goods
- Improved work efficiency
- Waste. [ITU-T L.1480]

11 Roadmap for green and low carbon development of the metaverse

In order to achieve the environmentally sustainable development of the metaverse, the goal is to control the capacity demand value of this field within the range that the Earth's ecosystem can bear. To achieve this goal, the following are suggested solutions from multiple industries and perspectives.

11.1 Establishment of green and low carbon ecosystem

The development of metaverse and digital industrialization should put green and low-carbon in a primordial position. It is necessary to focus on reducing the energy consumption of new infrastructure and improving the supply of clean electricity, as well as technological advantages, geographical environment, resource endowments, and location characteristics, in the careful consideration of digital industry development and construction.

11.2 Accomplishment of a green supply-chain

In order to achieve green and low-carbon development in the metaverse, it is necessary to establish a circular economy model, realize the environmentally sustainable development and application of software and services, and improve the effective use of resources and sustainable consumption choices. Taking the power supply chain as an example, all physical assets, such as materials, shelves, equipment, and vehicles, can be connected to intelligent sensors. Information will be embodied in the virtual world, combined with the virtual information of assets in other related industries, such as manufacturing and circulation in the society, to form a complete and "real" power supply chain operation picture.

11.3 Advancement of low carbon metaverse infrastructure

Building new networks such as 5G-A/6G, gigabit optical network/10 gigabit optical network, FTTR, and satellite Internet is recommended to meet the application requirements of high-speed, low-latency, and full-range three-dimensional coverage of the metaverse. A new type of computing power that integrates cloud and edge, computing and network, intelligent scheduling, green and low-carbon, and provides computing power guarantee for ultra-high content fidelity and real-time interaction freedom of the metaverse is needed. In addition, a comprehensive management platform for metaverse infrastructure to achieve distributed collaboration of computing, storage, communication capabilities, improve operational efficiency and reliability is to be established.

11.4 Harmonization through international standardization work

Numerous published technical specifications and reports on the metaverse have been issued and approved by ITU-T's Focus Group on the metaverse, especially on definitions, application scenarios, and use cases. Future work must integrate such work with the existing standardization efforts on green and low carbon development in ITU-T SGs dealing with the environment, climate change, circular economy, smart cities, and IoT to enhance the metaverse sustainability. Specific topics are of utmost importance:

a) Environmental sustainability metrics and indicators, along with methodologies;
b) Environmentally sustainable design practices for the metaverse;
c) Technical design guidelines to promote the use of green technologies and practices in the metaverse.

12 Conclusion

Numerous published technical specifications and reports on the metaverse have been issued and approved by ITU-T's Focus Group on the metaverse, including a definition, application scenarios, use cases. Future standardization work in ITU-T Study Groups should leverage the work of the Focus Group on metaverse. ITU-T Study Group 5 deals with the environment, climate change, circular economy and ITU-T Study Group 20 on IoT and smart cities & communities are expected to expand their work and address issues related to improving the sustainability of new emerging technologies. Specific topics that should be studied in the future include:

a) Environmental sustainability metrics and indicators, along with the development of methodologies
b) Environmentally sustainable design practices for the metaverse
c) Technical design guidelines to promote the use of green technologies and practices in the metaverse

Based on the findings of this technical report, the following points are to be noted for future work:

12.1 Energy consumption and GHG emissions will be fast increasing with the proliferation of metaverse applications

Due to the advancement of auxiliary products (e.g., smart glasses) that are manufactured to make suitable applications of the metaverse, more power consumption and GHG emissions are noted through the life cycle (from resource extraction to end-of-life treatment).

To mitigate the fast increase of power consumption and GHG emissions of the metaverse, strategies on renewable energy utility, power efficiency promotion, e-waste management, and GHG emissions accounting are to be adopted.

12.2 Metaverse application can enable industrial sectors to be green and low carbon in future development

From the perspective of ICT enablement in different industries, many activities can be optimized in operation, service, and maintenance with less environmental cost through the deep application of the metaverse.

12.3 Importance of metaverse assessment

The thorough study of green and low-carbon development of the metaverse necessitates relevant evaluations or assessments of the outcome of metaverse applications to different vertical sectors or entities. From the perspective of the future development of the metaverse in a systematic way, it is significant to consider international standardization development to promote large-scale applications, build green electronic supply chains, and innovate emerging technology.

Appendix I

Case study on green and low carbon development by application of metaverse in industry

[b-Metaverse Industry]

I.1 Energy industry: unattended inspection

In order to ensure the safety and stability of the production process, the energy industry attaches great importance to inspection work. Its particular industry scenarios not only result in high time and financial costs of inspection work but also pose significant health and safety risks to employees dealing with, for examples, ultra-high voltage transmission networks, offshore drilling platforms, or even oil pipelines in the desert.

By combining drones, underwater robots, pipeline robots, and VR technology, functions such as map navigation, voice recognition, automatic photography, and remote interaction can be achieved. With the help of VR glasses, power workers can collect, record, analyse and process actual data on power equipment automatically, and support remote consultation with an expert to guide electric energy workers in handling on-site problems. The combination of VR virtual reality and energy industry inspection has improved the safety of inspection personnel, allowing for the detection of defects that are difficult to detect manually. The efficiency and quality of equipment inspection have improved significantly, and the human interaction intensity has been reduced significantly. Inspection efficiency has also improved, ensuring better operation and maintenance conditions of production equipment in energy enterprises.

I.2 Mining Industry: Production Safety Training

Mining production provides important energy for economic construction; however, but in recent years, due to poor personnel safety awareness and low levels of self-rescue, mining safety accidents have occurred frequently, causing serious economic losses and casualties, which is not conducive to the stable development of society. As an important way to improve coal mine safety production, safety training can eliminate safety hazards in the coal mine production process, enhance the safety prevention awareness of coal mine employees, and promote the safe operation of coal mine production.

VR production safety training can provide training for mining workers' pre-employment operation and safety education, virtualize underground working conditions and dangerous situations, allowing trainees to experience them firsthand and learn to take effective emergency measures to deal with various dangerous situations, improve personnel quality, and eliminate accident hazards. After wearing VR headset, it feels as if they are in person, and the entire mine is vividly displayed in front of them. This provided a more realistic experience for the participants, allowing them to see directly the occurrence of coal mine accidents and the environment in the coal mine. This effectively solves the problem of difficulty in centralized training in coal mines and enables workers to have a clearer understanding of the underground environment in coal mines.

I.3 Discrete Manufacturing: VR Collaborative Design

The more complex industrial products are, the more urgent the demand for collaborative design becomes. For example, the number of parts involved in the construction of large, fixed- wing aircraft is generally 4 million, with more than 70000 drawings and more than 200 km of pipelines. All of parts must be assembled accurately and sequentially in different locations worldwide, relying on a globalized supply chain. Therefore, the risks caused by design deviations need to be identified and eliminated as soon as possible. Testing in real environments is difficult and expensive, and multiple companies and different departments must collaborate to design each individual part and conceive the final large-scale product.

With the help of the VR collaborative design platform, aircraft design will become simpler in the real world. Each manufacturer can embed equipment models and conduct virtual assembly tests with other companies' spare parts in the metaverse. The immersive experience brought by the metaverse can help designers feel the materials’ strength and even temperature more intuitively. The VR collaborative design platform designed for aircraft designers and engineers can enable different aviation contractors to work together in the same virtual environment, even if they do not use the same process design software to create their parts or they are not on the same site (or country/region), The above work can also be completed through the VR collaborative design platform.

I.4 Logistics industry: unmanned ocean shipping

The key capability of unmanned ships is the ability to perceive and communicate the conditions that are happening around them, enabling them to perform complex operations, avoid collisions along the way, and navigate smoothly to their destination. The shipping industry is committed to situational awareness systems, combining images from high-definition visible light and infrared cameras with Light Detection and Ranging (Lidar) and radar measurements to provide detailed images of the surrounding environment of ships. Then, this information can be transmitted back to the remote-control centre and handed over to an experienced captain for judgement. Or it can be processed directly by the unmanned ship's computer and a decision taken on what to do next.

The autonomous navigation system of a remotely commanded captain or unmanned vessel can also utilize information from many sources, such as correction information from satellite navigation, weather conditions, location and identity broadcasts of other vessels. The use of data from multiple sources and electronic assistance has become a part of the crew's daily activities. The system used to monitor the main mechanical conditions of ships and ensure the normal operation of engines and other key mechanical components has already assisted in determining navigation plans on board.

In the future, sensors embedded deep in critical systems of ships will provide more data, covering monitoring areas such as main engines, cranes and other deck machinery, propellers and bow thrusters, generators, fuel filtration devices, and more. This information will help determine whether these systems are working properly and effectively. When critical components are about to fail, the next port can be called to arrange preventive maintenance, and if necessary, personnel can be dispatched to board the ship for maintenance during the voyage.

I.5 Automotive Industry: A New Product Form and Business Model

The capital and technology-intensive auto industry is blessed with new energy and driverless technology. When others are still spinning around in the concept of the metaverse, the car industry with a keen sense of smell has been put into practice. Recently, alternative fuel vehicle enterprises have laid out the metaverse in succession. A Chinese brand vehicle enterprise plans to combine NFT to create a metaverse space integrating real cars and virtual cars, trying to find a feasible path to perfectly combine the entity with the metaverse so that the metaverse can gather more and more rich elements and become three-dimensional and diverse.

Firstly, the car company utilizes CPS technology and blockchain technology to verify the value of user data while protecting user privacy. A virtual currency (named "raw stone") is used to create value for the car data and to reward users for their data contributions. When the owner buys a car, they will own a real-world car that can drive and a digital twin virtual car that exists in the metaverse.

Secondly, the car company builds a metaverse ("Original Stone Valley") based on hybrid reality, in which real cars are connected with virtual cars. At present, users can obtain "raw stones" in two ways: through program mining, users can obtain raw materials for every km travelled; Nurturing mining involves participating in online and offline activities to cultivate virtual cars and obtain raw stones. Through the "Original Stone Valley", users can freely shuttle between the real and virtual worlds to enjoy the dual fun of space travel and time travel.

Ultimately, users can exchange real car products and services through "raw stones" to meet their daily needs. They can also exchange rights in the virtual world to meet spiritual needs. In this way, the driving data of real cars and the training data of virtual cars will be turned into real rights and interests, forming a closed loop of the industrial metaverse. While bringing value to users, it will also promote the iteration of automobile development technology of automobile enterprises, creating a win-win situation.

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