


## Article

# Hybrid Intelligence: Design for Sustainable Multiverse via Integrative Cognitive Creation Model through Human–Computer Collaboration

Yuqi Liu and Zhiyong Fu \* 

Academy of Arts &amp; Design, Tsinghua University, Beijing 100084, China; liu.yuqi.design@gmail.com

\* Correspondence: fuzhiyong@tsinghua.edu.cn; Tel.: +86-139-1109-2910

**Abstract:** The unprecedented development of artificial intelligence (AI) makes it possible for computers to imitate and surpass human intelligence (HI). Hybrid intelligence is the result of the co-evolution of AI and HI and has huge application potential in promoting the sustainable development of human society. This study starts from the similarities and differences between biological neural networks and artificial neural networks, compares the cognitive foundations of human intelligence and artificial intelligence, highlights the difference and connection between AI and HI, and puts forward the necessity and inevitability of their co-evolution to achieve hybrid intelligence with complementary advantages. Hybrid intelligence stands to become the pivotal force driving purposeful and planned sustainable creative behavior in the artificial intelligence era. This study proposes a design cognitive creation model based on human–computer collaboration that considers computational design thinking as the central concept. Moreover, the paradigm shift of design under hybrid intelligence intervention are explored from five aspects: “tool evolution”, “response mode”, “output result”, “iterative optimization” and “system innovation”. Finally, this article constructs a creative intervention mechanism of design creation driven by hybrid intelligence and discusses its role playing in the design activities of sustainable multiverse construction in the future. The proposal of the multiverse model transcends the confines of the metaverse’s virtual worldview and embraces sustainable development for value guidance. It advocates a future trajectory for humanity that hinges on technological progress, fostering a prosperous, balanced, and harmonious coexistence between the natureverse, socialverse, and digitalverse. This approach is not only rational and scientific, but also inherently sustainable.

**Keywords:** hybrid intelligence; artificial intelligence; human–computer interaction; computational design thinking; design cognition model; sustainability; SDGs; multiverse; design futures



**Citation:** Liu, Y.; Fu, Z. Hybrid Intelligence: Design for Sustainable Multiverse via Integrative Cognitive Creation Model through Human–Computer Collaboration. *Appl. Sci.* **2024**, *14*, 4662. <https://doi.org/10.3390/app14114662>

Academic Editor: Antonio Fernández-Caballero

Received: 7 April 2024  
Revised: 21 May 2024  
Accepted: 27 May 2024  
Published: 29 May 2024



**Copyright:** © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Cognition determines how humans understand and transform the world. Cognitive science has been a highly respected emerging science since the 20th century, focusing on the study of cognitive processes and their laws [1,2]. It includes six research directions: artificial intelligence, philosophy of mind, cognitive psychology, cognitive linguistics, cognitive anthropology, and cognitive neuroscience, with a focus on various phenomena behind the human brain and its work [3]. Design is a human-centered creative behavior with purposes and planning. Because cognition is the behavior of human learning, thinking, and understanding, design activities are based on cognitive science, and the process of design is also a process of logical thinking [4,5]. Since the 1960s and the 1970s, international scholars have conducted design research in numerous fields, such as cognitive science, design computing, computer-aided design, and human–computer interaction, exploring the inherent laws of creative thinking activities and achieving fruitful results [6].

Owing to our highly evolved brains, human beings are the smartest creatures on Earth [7]. The behavior of humans in understanding and transforming the world is the

result of their brain activity [8]. With the development of artificial intelligence, computers have made a qualitative leap. The maturity of GAN technology has led to the emergence of creativity in AI [9]. Numerous generative artificial intelligence tools have enabled AI to generate multimodal content, such as texts, images, 3D models, sounds, videos, and games, which has a huge impact on human creative activities, especially design [10]. From then on, creation is not only the behavior of human intelligence but also the behavior of artificial intelligence [11,12]. In the future, the intelligence of AI is expected to reach almost the same level as humans, or even surpass human levels, and even achieve consciousness awakening, thus becoming a new artificial species [13]. The unprecedented development of deep learning has shaped new human–computer relationships and evolved new forms of human–computer collaboration, with artificial intelligence and artificial intelligence responding to complex design challenges and solving problems in complementary ways [14]. This opens new possibilities for the sustainable development of human society. Design activities are increasingly presenting hybrid intelligent creation modes. Hybrid intelligence refers to the combination of human intelligence and artificial intelligence systems, utilizing their respective advantages to achieve more efficient and accurate decision making and sustainable work outcomes [15,16]. Through this approach, we can combine human creativity, intuition, and emotional intelligence with the high-speed computing, data processing, and automation capabilities of artificial intelligence, unleashing the maximum potential of both parties. Hybrid intelligence is no longer just a fusion of biology and machinery but an organic whole that simultaneously integrates multiple domain factors and information, thereby enhancing system perception, cognition, and action abilities.

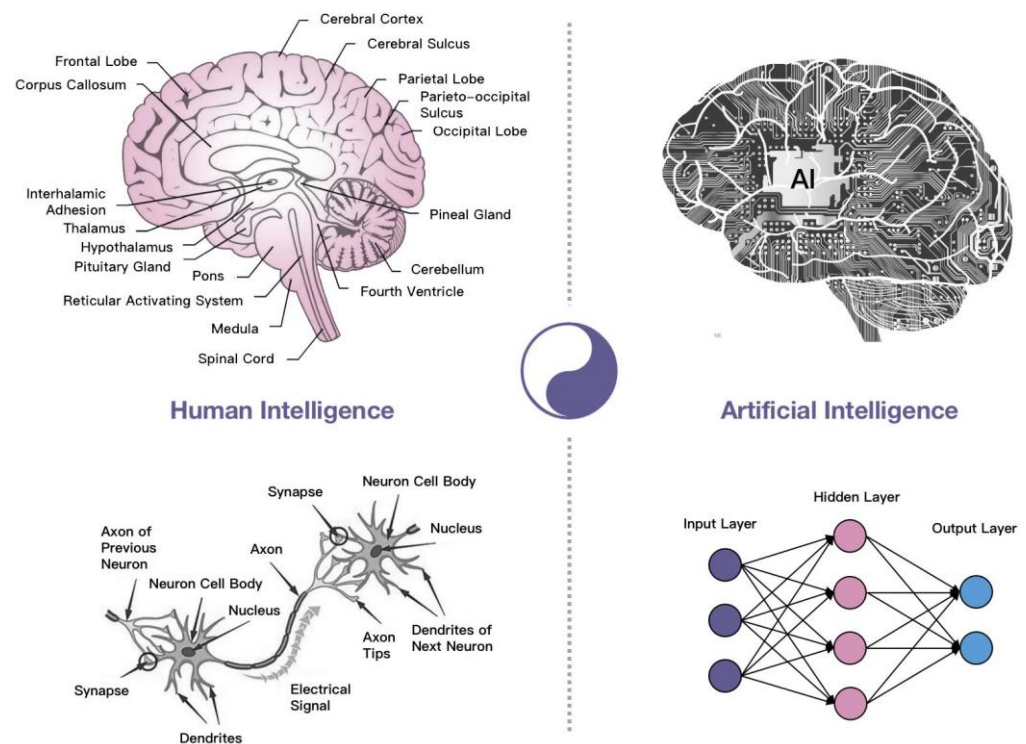
To delve into the challenges and opportunities that hybrid intelligence poses for sustainable creative endeavors, this study initially delves into the cognitive underpinnings of both human intelligence and artificial intelligence, comparing their similarities and differences. Subsequently, a design cognitive creation model, which seamlessly integrates HI and AI, is proposed. By tracing the evolution of production tools and methods across various stages of human society, this study identifies the shifts in mainstream design paradigms in the artificial intelligence era. Additionally, it explores the broadened scope of design activities enabled by hybrid intelligence and how it serves as a pivotal driving force in shaping a sustainable multiverse, encompassing the digitalverse, natureverse, and socialverse, in the future.

## 2. The Cognitive Foundations of Artificial Intelligence and Human Intelligence

The basic structure of artificial intelligence is an artificial neural network (ANN) [17]. Artificial neural networks are directly inspired by biological neural networks and partially mimic their principles and patterns of biological neural networks [18]. Neural networks are a series of algorithms that strive to identify potential relationships in a set of data by simulating the process of human behavior and can adapt to changes in the manner in which the human brain operates [19,20]. The human brain is composed of 86 billion nerve cells called neurons [21]. Each neuron is connected to one thousand other cells through axons. Dendrites receive stimuli/inputs from the external environment. When an input signal is received, an electrical pulse is generated and rapidly propagated through the neural network. The message can be sent to other neurons to handle the problem or forwarded [22]. It is believed that if the correct connections are established, artificial neural networks can also work in the same way, which can be simulated using silicon and wires in artificial intelligence, such as living neurons and dendrites in humans, as shown in Figure 1.

These technologies can solve complex signal processing or pattern recognition problems, such as voice-to-text transcription, facial recognition, weather prediction, and handwriting recognition for checking processing or data analysis. In neural networks, there are a large number of processors running in parallel, arranged at a hierarchical level. The original input information was received by the first layer, which is similar to the optic nerve in human visual processing. All subsequent layers receive output from their predecessor layers; similarly, neurons far from the optic nerve receive signals from neurons that rely

on the myopic nerves. The output of the system was generated by the last layer of the program [23]. Each processing node is composed of a small range of knowledge and rules embedded, programmed, and developed independently. Artificial neural networks (ANNs) are composed of multiple nodes that mimic the biological neurons in the human brain. Neurons interact through links that connect them. The node obtains input data and performs a single operation on the received data. The output of these operations is passed on to other neurons. The output of each node is called an activation or node value. Each link is associated with a weight. These artificial neural networks can learn every new experience, that is, the data they process, which is achieved by changing the weight values [24].



**Figure 1.** The cognitive foundations of artificial intelligence and human intelligence. Note: the figure is drawn by the authors.

As shown in Figure 1, the foundation of artificial intelligence is the mechanical brain, whereas the foundation of human intelligence is the human brain. The formation of the mechanical brain is the result of the development of human brain intelligence, and its construction principle comes from the imitation of the biological neural working mode of the human brain. Based on the similarities and differences in the structural and functional principles of artificial intelligence and human intelligence, each has its advantages and disadvantages. We need to have a more comprehensive and objective understanding of the relationship between artificial intelligence and human intelligence and explore how to combine the two to achieve better human–machine collaboration.

### 3. The Differences between Human Intelligence and Artificial Intelligence

The theory of artificial intelligence began with the concept of machines imitating humans. It enables computers to realize functions such as cognition, recognition, analysis, and decision making [25]. Its essence is to help humans solve problems and create solutions that are similar to or even beyond human thinking patterns [26]. Overall, the similarities and differences between artificial intelligence and human intelligence can be summarized as follows:

- (1) **Information processing:** Artificial intelligence can process information faster than humans can in specific tasks. In complex data analysis and graphic impact recognition, artificial intelligence performs faster and more accurately and can complete ultra-complex operations in an extremely short time. In other aspects, artificial intelligence may exhibit very low levels of intelligence, but for humans, it is very easy to handle.
- (2) **Knowledge field:** AI will surpass human ability in some specific fields such as playing Go, mathematical computing, natural language processing, and other tasks. Artificial intelligence has no memory bias, can continuously accumulate knowledge and experience, and ensures that knowledge in related fields is called up at any time.
- (3) **Learning ability:** Artificial intelligence can learn from a large amount of data and analyze and process various complex situations through machine learning and deep learning methods. Humans can acquire knowledge through self-learning and exploration and quickly adapt to new environments. In future developments, it is worth exploring how to combine machine-learning capabilities with human intelligence.
- (4) **Physiological characteristics:** Artificial intelligence has no limit to fatigue and can carry out the same thing tirelessly for a long time without fatigue under high-intensity labor; at the same time, artificial intelligence can operate and work in harsh environments without proper living conditions, such as a lack of air, food, and water, high temperatures, and pressures.
- (5) **Emotional cognition:** Humans can perceive and understand the emotions of others, but current artificial intelligence lacks this ability and is temporarily unable to possess human subjective abilities such as inspiration, feeling, or human cross-domain reasoning and drawing analogies. They rely only on data and experience to create or solve problems. There are no subjective factors, such as emotions.
- (6) **Moral ethics:** Human beings are social animals with strong moral ethics and concepts of right, wrong, good, and evil. They have an innate sense of beauty. As a product of human intelligence, artificial intelligence itself does not have a subjective sense of morality and ethics, which is one of the fundamental differences between humans and machines.

Human knowledge, experience, and energy are limited, and few or no one can solve the same problem for a long time. Simultaneously, the complexity of the problem directly affects the final solution of the solver. When the problem solver cannot find an optimal solution, the proposed solution has a certain degree of subjectivity and may even be incorrect. However, there are exceptions where people have magical skills—inspiration and intuition—that can help them find shortcuts to solving problems in a short period. From a design perspective, as artificial intelligence accumulates experience in different fields, its insight into the relationships between things will gradually improve, and the repetition of this process will continuously feedback on its ability to solve problems. When the computing power, analytical ability, and insight of artificial intelligence surpass those of humans, the solutions provided by artificial intelligence in many fields will be superior to those of humans. Therefore, artificial intelligence will ultimately surpass humans in solving super complex and purely intelligent problems and can produce formulaic designs, such as graphic designs, web pages, and mobile interaction designs that meet specific standards and can be mass-produced.

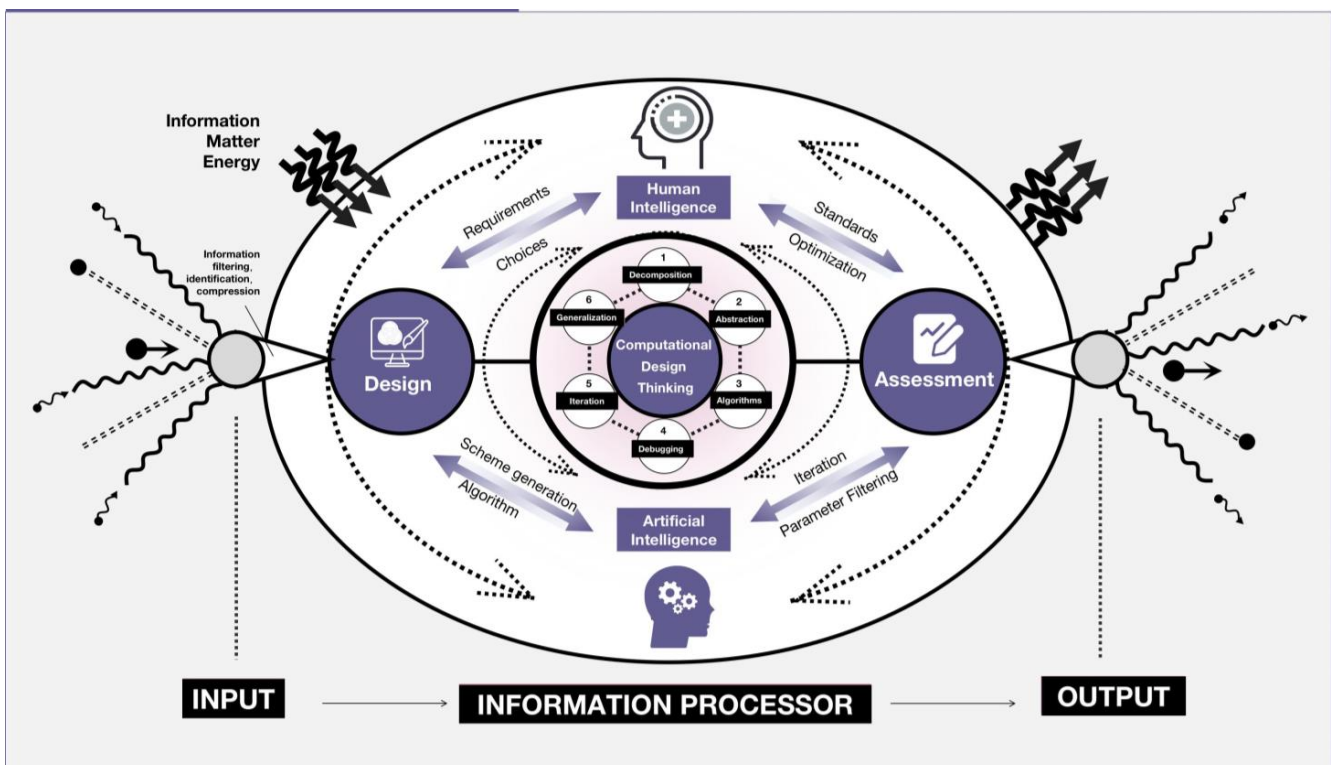
In summary, artificial intelligence has more advantages than humans in solving complex and purely intellectual and physical problems, while humans have more advantages in understanding and feeling emotions, morals, and ethics than artificial intelligence. Therefore, developing a hybrid intelligent social technology combination for human–machine integration is important and necessary [27]. However, for artificial intelligence, designers do not have to worry too much about being replaced because their job is to improve experience and satisfaction, both of which are subjective. At the same time, in addition to solving problems, design involves understanding and creating beauty. Beauty is the experience and perception of beauty, which is complex and includes objective and subjective factors, such as history, culture, environment, and emotions. Therefore, people with different cultural

backgrounds and personality traits in different eras, classes, ethnic groups, and regions have different definitions of beauty, which is difficult to measure using artificial intelligence. In summary, both human intelligence and artificial intelligence have their own advantages and disadvantages and can complement each other’s strengths to shape a hybrid intelligent creation model of human–machine collaboration for the future [15].

#### 4. The Design Cognitive of Hybrid Intelligence

Design has often relied on human ingenuity; however, over the past decade, the field’s toolbox has expanded to include methods from artificial intelligence and its related fields, opening up space for hybrid intelligence-driven design creation that emphasizes the importance of human–computer cooperation [28]. This section will start from the cognitive basis and explore the cognitive model of hybrid intelligence design that integrates artificial intelligence and human intelligence. Artificial intelligence can be divided into weak AI, strong AI, and super AI based on their ability. The development of artificial intelligence technology will have an increasingly important impact on human creative activities. The higher the level of AI development of artificial intelligence, the stronger the design intervention it can bring, demonstrating a trend from computer-aided design to AI-driven design.

Jarrahi et al. proposed how humans and artificial intelligence can enhance their abilities and intelligence through collaborative interactions (i.e., human-enhanced artificial intelligence and AI-enhanced human intelligence by comparing artificial intelligence with human intelligence), resulting in hybrid intelligence [29]. Figure 2 presents the evolutionary pattern of hybrid intelligence design cognition that integrates human and artificial intelligence, which considers computational design thinking as the core. It combines human design thinking principles with computer thinking, tools, and technologies to promote creative problem-solving and decision-making processes.



**Figure 2.** The design cognitive model of hybrid intelligence via human–computer collaboration. Note: the figure is drawn by the authors.

The core position in the middle of Figure 2 is computational design thinking, which is the most cognitively related thinking mode that integrates artificial intelligence and human intelli-

gence in design cognition. Computational design thinking takes computational thinking as the core of creation, and design thinking as the outer layer of decision making. Computational thinking was first proposed by Professor Jeannette M. Wing of Carnegie Mellon University in 2006 in the ACM journal *Communications of the ACM* [30,31]. Computational thinking does not refer to the ability of mathematical calculation. Nor do they refer to the ability to use computers. Computational thinking is a process of solving problems that absorbs the general mathematical thinking methods used to solve problems and is conceptual rather than procedural [32]. Computational thinking is a series of thinking activities covering the breadth of computer science, such as problem solving, system design, and understanding human behavior, using computer science thinking [33]. In 2011, Professor Zhou Yizhen updated the definition of computational thinking, pointing out that computational thinking is a thinking process related to formalized problems and their solutions, and that the representation of problem solving should be effectively executed by information processing agents [34].

The process of computational thinking includes six aspects: decomposition, abstraction, algorithms, debugging, iteration, and generalization. As shown in Table 1, the decomposition step is mainly to decompose a complex problem and obtain its basic elements; the abstraction step is mainly used to model the core aspects of a problem and obtain the component module; the algorithms step is mainly aimed at generating ideal design schemes in an orderly manner and obtaining arithmetic logic; the debugging step is mainly to identify and fix errors, and complete error correction; the iteration step is mainly aimed at dynamically optimizing all repetitive elements or sequences to obtain system structure optimization; the generalization step is mainly aimed at extending the solution of a specific problem to other problem-solving processes of the same type, and generating a new system.

**Table 1.** The core process of computational design thinking.

Steps	Process	Result	Explanation
Step 1	Decomposition	Basic Element	Breaking a complex problem down into smaller parts
Step 2	Abstraction	Component Module	Modeling core aspects of a problem
Step 3	Algorithms	Arithmetic Logic	Producing desired solutions sequentially
Step 4	Debugging	Error Correction	Identifying and fixing errors
Step 5	Iteration	Structure Optimization	Optimize all the repeating elements or sequences dynamically
Step 6	Generalization	System Generation	Extending a solution for a particular problem to other kinds of problems

If designers are regarded as representatives of human intelligence innovation and creativity, their role is similar to that of information processors. They receive information from the external environment, undergo orderly processing, and produce artificial objects that continue to act in the external environment. In Figure 2, human intelligence and artificial intelligence jointly form the designed information processor, and the external environment exchanges information with the information processor through information flow, material flow, and energy flow. In information processors, human intelligence is responsible for inputting design requirements, whereas artificial intelligence is responsible for editing algorithms according to requirements and outputting solutions for requesters to choose from. At the same time, human intelligence sets standards for design quality. Artificial intelligence encodes the standards into parameters, filters the design scheme, and iteratively optimizes it to produce optimized design solutions that meet human requirements.

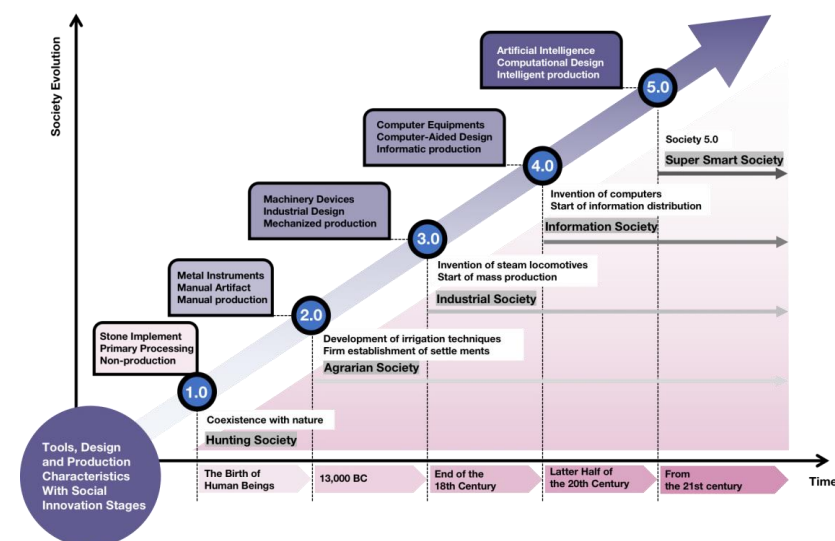
This process can be performed iteratively within the information processor until a satisfactory design solution is output to solve design problems through advanced computer processing. Every step of the designer's workflow was translated into an encoded computer language. Software programs use this information and project-specific parameters to create algorithms for generating design models or completing design analyses. Once the initial programming is completed, design becomes a dynamic, modifiable, and repeatable process. The iterative and people-oriented nature of computational design thinking ensures that the evolution of intelligent systems is consistent with human needs and desires and is also the carrier and embodiment of the concept of "human-centered AI".

## 5. Design for Multiverse via Hybrid Intelligence Creation Mode

### 5.1. The Evolution of Human Society, Production, and Design Tools

Design is the sum of human thinking and experience [35], such as the shaping of spatial experience in architectural design, the perception of beauty in daily life in product design, and the connection between information and human thinking in interface design. Since the emergence of computers, technological innovation has expanded capabilities through innovative design and production tools [36]. From a technical perspective, the evolutionary history of design, from stone blocks to screen printing, is traditional. The principle is that designers use human thinking to assist in design through tools, and the achievable goals are mostly the extension of human physical abilities. However, the rise of artificial intelligence and computational design is based on the use of human-machine-integrated computer thinking for design, with achievable goals often being the extension and enhancement of human brain abilities.

Figure 3 shows the evolution of tools, design types, and production at different stages of human society. In the early primitive hunting era, our ancestors had similar survival patterns to other animals and gradually evolved to use simple stone, bone, and wooden tools. At this time, the type of creation was based on the original form of the object and was basically self-sufficient, without a relatively large-scale production mode. In 13,000 BC, humans entered an agrarian society, accompanied by the rise of metal tools such as ironware. Design work was mainly reflected in traditional handcrafting, and a manual production model of barter and currency circulation emerged. At the end of the 18th century, the birth of the steam engine marked that humankind had entered the industrial era, and social productivity had been greatly improved because of the birth of machinery and equipment. With the generation of electricity, the power source driving machinery has gradually evolved from steam-driven to electric-driven. Simultaneously, industrial design emerged, with a large number of electrical appliances being designed and produced, resulting in a mass industrial production model. In the second half of the 20th century, computers marked human beings who had entered the information age, followed by the birth of artificial intelligence, which was relatively weak in intelligence, and the occupation of designers. The role of computers in design is dominated by computer-aided design, and an information production model is derived. In the 21st century, artificial intelligence technology has made tremendous progress, AI capabilities have been greatly strengthened, computing power and creativity have rapidly increased, and humanity has entered the era of artificial intelligence. Computers have shown a trend that surpasses human intelligence, resulting in emerging design types such as parametric, generative, and algorithm designs represented by computational design. In particular, the AIGC in these years will bring great changes and impacts to future design education and design practices.



**Figure 3.** The evolution of human society, production, and design tools. Note: the figure is drawn by the authors.

## 5.2. *The Changes in Design Paradigms in the Era of Artificial Intelligence*

### 5.2.1. Tool Evolution—From “Body Tool” to “Brain Tool”

The emergence of artificial intelligence has led to the evolution of creative tools, from the initial expansion of designers’ physical abilities to the current expansion of their brain abilities. Artificial intelligence becomes an intelligent enhancement tool for a designer’s brain, and this process requires four stages. First, in the perception stage, artificial intelligence perceives and recognizes the physical environment that the designer is exposed to through sensors and computer vision technology, thereby obtaining a preliminary understanding of design problems. Second, in the cognition stage, artificial intelligence utilizes natural language processing and machine learning to understand and explain the knowledge involved by designers, thereby gaining a deeper understanding of design problems. Third, in the innovation stage, artificial intelligence can autonomously generate multiple design schemes through Generative Adversarial Networks (GANs) and continuously optimize design solutions through interaction and feedback with designers. Fourth, in the decision-making stage, artificial intelligence can autonomously select an optimal design scheme based on the preferences and goals of designers through reinforcement learning and related technologies. The design scheme can be implemented through collaboration and communication with designers. Through continuous iteration and optimization in the above four stages, artificial intelligence design tools have become effective assistants and creative partners for designers through hybrid intelligence.

### 5.2.2. Response Mode—From “Passive Response” to “Active Generation”

The rapid development of artificial intelligence has led to the transformation of a computer’s response to a designer’s command input, from an early passive mode to a later active generation. Artificial intelligence has the ability to self-learn, self-repair, and self-regulate, which can explore and discover design patterns and trends independently through learning and analyzing a large amount of data, thereby generating design solutions that meet the requirements of designers. Traditional computer-aided design (CAD) software responds passively based on the designer’s instructions, such as accurate drawing and modification according to the designer’s drawing commands. Artificial intelligence design tools, on the other hand, can learn historical design data through machine learning algorithms, thereby gaining a deeper understanding and mastery of design problems as well as the preferences, styles, and needs of designers. Based on these learning outcomes, artificial intelligence design tools can proactively propose, optimize, and adjust design solutions based on the designer’s feedback. Thus, designers can not only gain more design inspiration and support but also complete design tasks more efficiently. Therefore, the active generation ability of artificial intelligence design tools makes them no longer simple drawing tools but intelligent assistants and creative partners for designers, greatly improving their design level and work efficiency.

### 5.2.3. Output Result—From “Materialization of Digital Things” to “Digitalization of Material Things”

The design in the era of artificial intelligence can be summarized as two aspects: “materialization of digital things” and “digitization of material things”, using design to build smoother and more effective communication channels between the digital world and the physical world. The “materialization of digital things” refers to the design of how the content of digital things can be expressed through human touch, perception, and interaction, including dimensions such as digital modeling, digital creativity, and digital visualization. By collaborating with data and software engineers, designers present products or data through modeling or visualization systems, assisting managers in optimizing resource allocation from a comprehensive perspective, improving the overall design and construction efficiency, and reducing user cognitive barriers and product expansion costs. Another design pattern is the “digitization of material objects”, which includes digital

twins and digital design. With the development of data visualization to a deeper level, it is necessary to establish a more effective mapping between the digital world and the material world, reconstruct and present the data of the material world in the virtual world through algorithms and modeling processing, and use digital technology to simulate the behavior of physical objects in the real world to assist managers in the overall system state control.

#### 5.2.4. Iterative Optimization—From “Static Scheme” to “Dynamic Simulation”

Owing to the intervention of artificial intelligence technology, iterative optimization of design is undergoing a transition from static solutions to dynamic simulations. This transformation is mainly reflected in the following three aspects: the design process is more intelligent, the design results are more humane, and the design efficiency has significantly improved. For example, in the field of graphic design, artificial intelligence can analyze user behavior through big data, automatically generate advertising posters with brand colors, and generate design solutions suitable for different users. This makes the designer’s workflow more efficient while also making the design more targeted and attractive. In the field of web design, AI can learn human preferences and design patterns using deep learning algorithms, thereby generating web design solutions that meet human needs. This makes web design more user-oriented and improves the user experience. In the field of interior design, artificial intelligence can automatically generate design solutions that meet human aesthetic and comfort needs based on factors such as room size, lighting, and furniture. This significantly shortens the design time of the designers and reduces human error. In the field of fashion design, artificial intelligence can automatically generate design solutions that meet customer needs based on their body shape, preferences, and style. This improves the design efficiency while also making the design more personalized and precise. In the field of architectural design, artificial intelligence can analyze factors such as the environment, terrain, and wind direction of a building, and automatically generate design solutions that meet human aesthetic and comfort needs. This not only improves the energy utilization efficiency of buildings but also makes the building design more reasonable and optimized.

#### 5.2.5. Systemic Innovation—From “Single Object” to “System Integration”

Design innovation in the era of artificial intelligence has changed from a single object to system integration. In traditional design, designers usually focus on the design of a single product or object, considering how to make an object have a unique functionality, appearance, and user experience. However, in the era of artificial intelligence, design thinking has expanded to the system level, and designers have begun to consider how to design and optimize the entire system, rather than just a single product or object. One of the reasons for this shift is that the rapid development of artificial intelligence technology allows designers to automate tedious tasks, such as data analysis and pattern recognition, thereby investing more energy in system design and innovation. In addition, artificial intelligence also enables designers to better understand and predict user needs and behaviors, thereby improving the design and optimization of systems. Another reason is the complexity and challenges of system design. In the era of artificial intelligence, the solution to problems usually requires the comprehensive consideration of multiple factors, including technology, economy, environment, and society. This requires designers to have more comprehensive knowledge and skills and to be able to think and solve problems from multiple perspectives. At the same time, this also requires designers to have stronger coordination skills to cooperate with professionals in other fields to jointly design and optimize systems.

#### 5.3. Design for Sustainable Multiverse with Hybrid Intelligence

Hybrid intelligence, as an intelligent model that integrates artificial intelligence and human intelligence, is the design core of a sustainable multiverse, reflecting the deep

integration of intelligent technology and cosmic concepts and has broad application prospects and potential. By leveraging the advantages of hybrid intelligence, we can better understand and manage this complex and ever-changing universal system to achieve innovative and sustainable development. Design is a creative activity centered on human beings, and hybrid intelligent design that integrates human intelligence and artificial intelligence has consistently expanded the multiverse space of design [37], providing unlimited possibilities for achieving sustainable human development goals from the perspective of intelligent technology. The creative activities of the future world are created by the hybrid intelligence of human-machine collaboration. At present, scholars and experts have explored the application of hybrid intelligence in different creative fields, such as intelligent assistants [38], the automobile industry [39], printing processes [40], e-commerce [41], product virtual prototyping [42], financial credit evaluation [43], industrial production [44], service innovation [45], global climate monitoring and control [13], epidemic control [13], etc.

With the continuous development of artificial intelligence (AI) technology, more realistic and rich virtual worlds are expected to be created. In the future, our world will present a state of deep integration of physical and virtual worlds. However, the construction of these two spaces is incomplete. Humans are humans because of their sociality. The activities of understanding and transforming the world are influenced and dominated by a huge invisible social network. In this study, we call this invisible social network the socialverse. When digital technology is extremely developed and digital living conditions are widely popularized, human identity presents multiple attributes of natural identity, digital identity, and social identity, and human beings become natural human, digital human, and social human. We refer to the total sum of people, things, and objects created by each different identity of human beings and their spatial and related activities as the natureverse, digitalverse, and socialverse, respectively. In this multiverse, the collaborative mode of human intelligence and artificial intelligence, represented by hybrid intelligence, has become the core control center and driving force. The relevant technical systems include artificial intelligence, big data, cloud computing, the Internet of Things, blockchain, robotics, 3D printing, and XR (VR, AR, MR) technology. In addition, the multiverse co-builders include individuals and groups such as large enterprises, start-ups, governments, organizations, investors, academic institutions, educational institutions, medical institutions, communities, governments, and citizens. Based on these stakeholders, the derived technology systems include urban, tourism, transportation, finance, education, agriculture, environment, family, food, law, work, retail, advertising, media, entertainment, health, sports, nursing, biology, government, citizens, and infrastructure technology systems, which together form the basis for supporting the development of the multiverse. We summarized the main types of design activities in the multiverse as green system design in the natureverse, digital system design in the digitalverse, and social system design in the socialverse. Here, the meaning of design represents the general planning activities of human beings. From the perspective of long-term value orientation, the multiverse development direction should be guided by global Sustainable Development Goals (SDGs). In this section, we introduce the 17 sustainable development goals of the United Nations facing the future and propose ways and strategies of hybrid intelligence to promote the fulfillment of the 17 sustainable development goals, as shown in Figure 4. The following section will focus on exploring the role and strategies of human-machine collaborative hybrid intelligent design in promoting sustainable multiverse development.

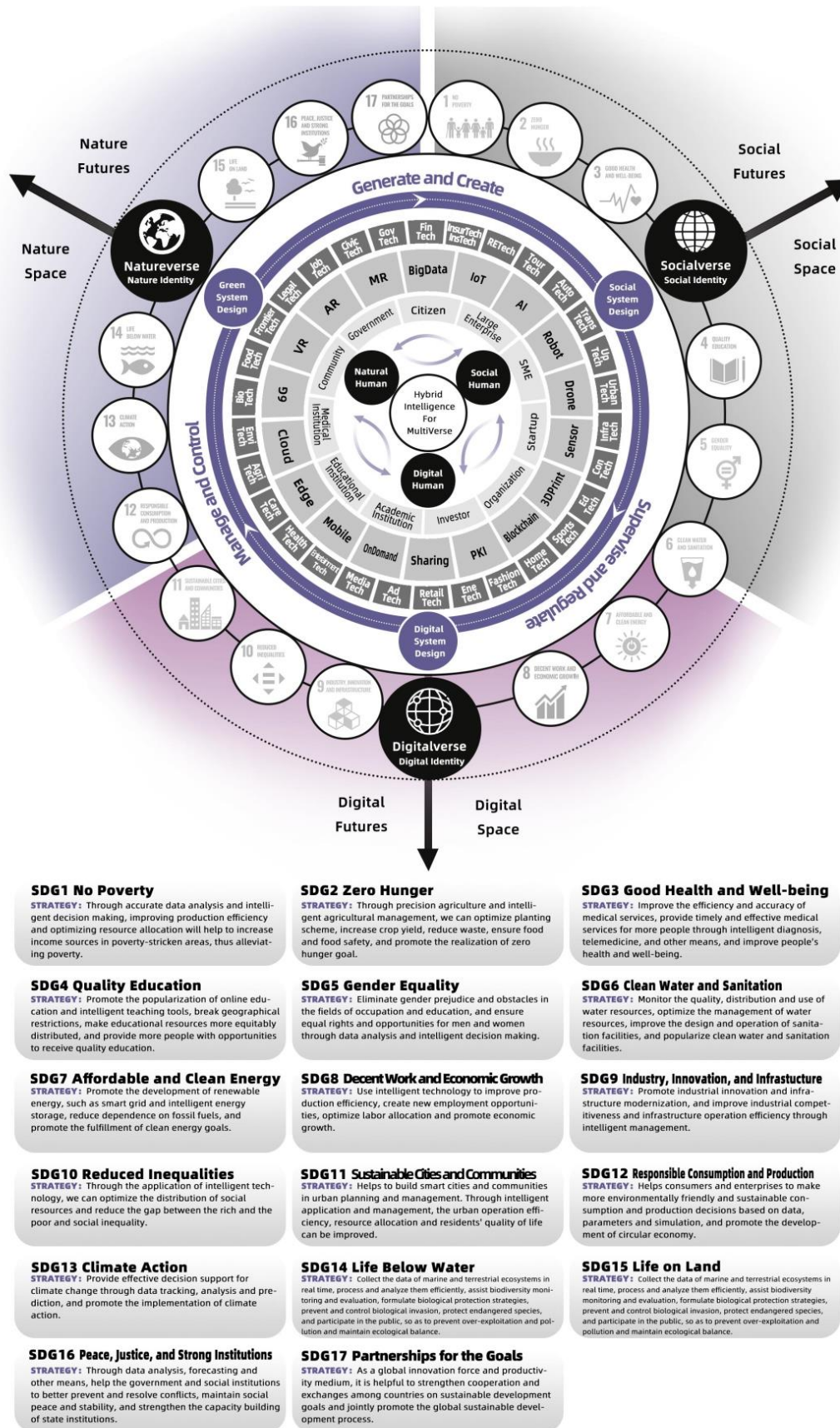


Figure 4. Design for sustainable multiverse via hybrid intelligence creation mode. Note: the figure is drawn by the authors.

### 5.3.1. Natural Human: Design for Sustainable Natureverse—Natural Futures

Human beings are natural beings, and the human body has an objective materiality. Hybrid intelligence can leverage human creativity, intuition, and emotions as well as the high-speed computing, data processing, and automation capabilities of AI to jointly drive problem solving and task completion. Designing for the natureverse through hybrid intelligence refers to the creative activities of human–machine collaboration in natural space, shaping the natural world. Green system design is a concept that emphasizes environmental protection and sustainable development, aimed at reducing adverse impacts on the environment, promoting effective utilization of resources, and improving the stability of ecosystems. It involves multiple aspects such as product design, environmental construction, and service system establishment, and follows the principles of social, economic, and ecological sustainability. Hybrid intelligence promotes the sustainable development of nature through green system design, which can be understood from the following aspects:

- **Optimize the utilization of natural resources.** Hybrid intelligence can use AI data analysis and optimization algorithms to accurately monitor and manage the use of resources in green systems to avoid resource wastage. For example, for SDG6 Clean Water and Sanitation, hybrid intelligence can help monitor the quality, distribution, and use of water resources, optimize water resource management, improve the design and operation of sanitation facilities, and promote the popularization of clean water and sanitation facilities.
- **Promote and maintain ecological balance.** Hybrid intelligence can help with green system design and implement ecological protection measures, such as ecosystem restoration and wildlife protection, to maintain ecological balance. Through the monitoring and prediction functions of AI, hybrid intelligence can discover and solve ecological problems in real time and reduce the negative impact of human activities on the ecosystem. For example, for SDG14 Life Below Water and SDG15 Life on Land, hybrid intelligence can collect data on marine and terrestrial ecosystems in real time through various sensor devices, conduct efficient processing and analysis, assist in biodiversity monitoring and assessment, biological protection strategy formulation, biological invasion prevention and control, endangered species protection, public participation, etc., prevent overdevelopment and pollution, and maintain ecological balance.
- **Innovate the application of smart green technology.** Hybrid intelligence can provide a new technological innovation direction for green system designs. Combining innovative human thinking and AI's automation ability, we can develop more efficient and environmentally friendly green technologies, such as clean energy technology and low-carbon building technology, to promote sustainable development. For SDG7 Affordable and Clean Energy, hybrid intelligence can promote the development of renewable energy, such as the construction of smart grids and intelligent energy storage, reducing the dependence on fossil fuels, and promoting the realization of the goal of clean energy.
- **Improve the efficiency of ecological decision making.** Hybrid intelligence can assist the decision-making process in green system design and provide scientific and reasonable suggestions for decision-makers through the data analysis and prediction function of AI to improve the efficiency and accuracy of decision making. This helps avoid shortsighted decision making and promotes long-term sustainable development. For example, for SDG13 Climate Action, hybrid intelligence can provide effective decision support for coping with climate change and promote the implementation of climate action through data tracking, analysis, and prediction.

In summary, hybrid intelligence can play an important role in green system design and promote sustainable development of the natural universe by optimizing resource utilization, promoting ecological balance, innovating green technologies, and improving decision-making efficiency. However, this process requires active human participation and supervision to ensure the correct application and development of hybrid intelligence.

### 5.3.2. Digital Human: Design for Sustainable Digitalverse—Digital Futures

Humans are digital beings, and the characteristics of digital survival are becoming increasingly obvious in the era of artificial intelligence. Human beings are increasingly transforming into digital entities in the age of artificial intelligence, with the hallmarks of digital existence becoming increasingly pronounced. The concept of designing the digitalverse via hybrid intelligence encompasses the collaborative efforts of humans and computers within the digital realm, jointly shaping the digital world. This type of design focuses on embracing individuals, objects, and environments in the digital space as its design targets, leveraging hybrid intelligent technology to explore and innovate the construction, management, and utilization of the digital world. The digitalverse serves as a virtual platform that mirrors diverse objects, occurrences, and processes of the real world in a digital format. This virtual realm offers a more encompassing, intricate, and interactive means of communicating information, while also unlocking boundless opportunities across multiple domains, including entertainment, science, and engineering. Hybrid intelligence technology empowers designers to craft more intelligent, tailored, and efficient user experiences in the digital world. Hybrid intelligence promotes the sustainable development of the digital system design, mainly reflected in the following aspects:

- **Optimize the utilization of digital resources.** Hybrid intelligence uses artificial intelligence algorithms to effectively manage and optimize digital resources to achieve the rational distribution and efficient use of digital resources. Through deep learning and data analysis, hybrid intelligence can predict the demand and supply trends of digital resources to avoid waste and shortage of resources and improve the sustainable utilization of digital resources. For example, for SDG3 Good Health and Well-being, hybrid intelligence can help improve the efficiency and accuracy of medical services and provide timely and effective medical services to more people through intelligent diagnosis, telemedicine, and other means to improve people's health and well-being. For SDG12 Responsible Consumption and Production, hybrid intelligence can help consumers and enterprises make more environmentally friendly and sustainable consumption and production decisions based on data, parameters, and simulation, and promote the development of a circular economy.
- **Improve the efficiency and reliability of digital systems.** Hybrid intelligence can be used to design more efficient and stable digital systems by combining human intelligence with the computing power of machines. By optimizing algorithms and intelligent monitoring, hybrid intelligence can reduce the energy consumption of digital systems, reduce hardware failures and maintenance costs, and improve the operational efficiency and service life of digital systems. For example, in the SDG9 Industry, Innovation, and Infrastructure, hybrid intelligence is the key force in promoting industrial innovation and infrastructure modernization. Through intelligent management, the competitiveness of the industry and the operational efficiency of the infrastructure are improved.
- **Innovate the application of digital technology.** Hybrid intelligence provides a new technological innovation path for digital system designs. Combined with AI, big data, cloud computing, and other advanced technologies, hybrid intelligence can develop more intelligent and environmentally friendly digital technology applications such as intelligent transportation, intelligent medical treatment, and intelligent cities to promote the sustainable development of the digital universe. For example, for SDG11 Sustainable Cities and Communities, the application of hybrid intelligence in urban planning and management helps to build smart cities and communities, improve urban operation efficiency and resource allocation, and improve residents' quality of life through intelligent application and management.
- **Promote data security and privacy protection.** In the digitalverse, data security and privacy protection are crucial. Hybrid intelligence can discover and respond to potential data security risks in real time through intelligent monitoring and risk

assessment, protect user privacy and data security, and provide a solid guarantee for the sustainable development of the digital universe.

In summary, hybrid intelligence can play an important role in digital system design and promote the sustainable development of the digitalverse by optimizing the use of digital resources, improving the efficiency and reliability of digital systems, innovating the application of digital technology, and promoting data security and privacy protection. However, in this process, we must pay attention to ethics, security, privacy, and other issues to ensure that the application of hybrid intelligence meets the requirements of social values, laws, and regulations.

### 5.3.3. Social Human: Design for Sustainable Socialverse—Social Futures

Human beings are social beings, and the typical feature that distinguishes humans from other species is their social nature. Designing for the socialverse through hybrid intelligence refers to the collaborative creative activities of humans and computers in social space to shape the social world. This kind of design takes social problems and social needs as the design objects or goals and aims to use advanced artificial intelligence and big data technology to reveal the operating laws and characteristics of society while simultaneously applying these laws to social governance, public services, social behavior understanding, and other fields. This kind of design needs to comprehensively consider various social factors and needs, which can help people to better understand and solve social problems and respond to the development needs of human society. It can also promote social progress and development to improve the overall benefits and well-being of society. Hybrid intelligence promotes the sustainable development of society through social system design, which can be elaborated from the following aspects:

- **Improve the efficiency and quality of social decision making.** Hybrid intelligence can be integrated into social decision-making systems. With the help of AI algorithms and big data analysis capabilities, decision-makers can quickly obtain and analyze the key information of social problems, as well as the related complex and hidden context. With the help of hybrid intelligence, the decision-making process can be made more scientific, reasonable, and efficient in improving the quality and accuracy of decision making. This will help avoid blind decision making and short-sighted behavior and promote the long-term sustainable development of society. For example, for SDG1 No Poverty, through accurate data analysis and intelligent decision making, we can improve production efficiency and optimize resource allocation, which will help to increase the source of income in poor areas, thereby reducing poverty.
- **Optimize resource allocation and fair distribution.** Hybrid intelligence plays an important role in social resource allocation. Through intelligent algorithms, hybrid intelligence can be used to analyze the supply and demand of social resources and propose a scheme for optimizing resource allocation. Simultaneously, hybrid intelligence can also consider the principle of fair distribution to ensure the rational distribution of social resources and reduce social injustice. This is conducive to the coordinated development of the social economy, society, and environment. For example, for SDG2 Zero Hunger, hybrid intelligence can optimize the planting scheme, improve crop yield, reduce waste, ensure food and food security, and promote the fulfillment of the goal of zero hunger through precision agriculture and intelligent agricultural management. For SDG8 Decent Work and Economic Growth, hybrid intelligence can create new employment opportunities, optimize labor allocation, improve production efficiency, and promote sustainable economic growth. For SDG10 Reduced Inequality, hybrid intelligence can optimize the allocation of social resources and reduce the gap between the rich and the poor and social inequality.
- **Enhance the ability of social management and governance.** Hybrid intelligence can improve the intelligence levels of social management and governance. Through intelligent monitoring, forecasting, and early warning, hybrid intelligence can help governments and social organizations better understand social conditions and discover

and solve social problems in a timely manner. Simultaneously, hybrid intelligence can also provide a scientific basis for policy formulation and implementation and improve the effectiveness and pertinence of policies. This will help enhance social management and governance and promote the harmonious and stable development of society. For example, for SDG5 Gender Equality, hybrid intelligence can eliminate gender biases and barriers in the fields of occupation and education through data analysis and intelligent decision making and ensure equal rights and opportunities for men and women.

- **Promote the development of education and culture.** The application of hybrid intelligence in the fields of education and culture can promote prosperity and the development of social culture. Through hybrid intelligent technology, we can achieve the precise push for personalized education resources and improve the quality and efficiency of education. Simultaneously, hybrid intelligence can also provide new means and platforms for cultural inheritance and innovation and promote the innovative development of the cultural industry. For example, SDG4 Quality Education promotes the popularization of online education and intelligent teaching tools, breaks geographical restrictions, makes the distribution of educational resources more equitable, and provides more people with opportunities to receive high-quality education.
- **Advance social innovation and international cooperation.** Hybrid intelligence can stimulate innovation vitality and promote cooperation and development in all fields of society. The application of hybrid intelligence can break the traditional thinking mode and industry barriers and promote cross-border cooperation and innovation. At the same time, hybrid intelligence can also provide members of international institutions and organizations with more convenient and efficient communication and cooperation tools, promote information sharing and knowledge dissemination, and promote human civilization and social progress. For example, for SDG16 Peace, Justice, and Strong Institutions, hybrid intelligence can help governments and social institutions better prevent and resolve conflicts, maintain social peace and stability, and strengthen the capacity-building of national institutions through data analysis, prediction, and other means. For SDG17 Partnerships for the Goals, hybrid intelligence, as a global innovation force and productivity medium, helps to strengthen cooperation and communication among countries on sustainable development goals, jointly build global partnerships, and promote the global process of sustainable development.

In summary, hybrid intelligence can actively promote the sustainable development of the social universe by improving the efficiency and quality of social decision making, optimizing resource allocation and fair distribution, enhancing the ability of social management and governance, promoting the development of education and culture, and promoting social innovation and international cooperation. However, in the application process, it is also necessary to balance the relationship between technological development and human values to ensure that the application of hybrid intelligence meets the requirements of social ethics, laws, and regulations.

To sum up, the role of hybrid intelligence in the development of a sustainable multiverse is reflected in the following three aspects: generation and creation, supervision and regulation, and management and control.

#### (1) Generation and Creation

First, understand and simulate the complexity of the real world. By combining the advantages of artificial intelligence and human intelligence, hybrid intelligence can better understand and simulate real-world complexity. In the multiverse, different universes and dimensions may have different physical laws, time, and space structures, as well as diverse life forms and civilizations. Hybrid intelligence can use the data processing, pattern recognition, and learning capabilities of artificial intelligence, as well as the creativity, intuition, and decision-making capabilities of human intelligence, to jointly explore and understand the characteristics of these verses. Second, generate digital content and build a realistic

virtual world. Hybrid intelligence plays a key role in the generation of a virtual world. By combining deep learning, computer graphics, physical simulations, and other technologies, hybrid intelligence can build a highly realistic virtual environment, including terrain, buildings, biology, and weather. These virtual worlds are not only visually realistic but can also simulate complex phenomena, such as physical interaction and behavioral logic. Hybrid intelligence can also generate virtual characters and provide intelligent behavior so that they can act, interact, and evolve independently in the virtual world. Third, create and provide new intelligent services and experiences. Hybrid intelligence also plays an important role in creating new services and experiences. In the multiverse, there may be various unknown resources, opportunities, and challenges. Hybrid intelligence can combine voice recognition, natural language processing, emotional computing, and other technologies to create intelligent assistants, consultants, and partners to provide users with personalized services, entertainment, and educational experiences. These intelligent systems can understand users' needs and preferences, provide accurate information, suggestions, and support, and help users better adapt to and explore the multiverse. Fourth, promote sustainable innovation and progress in the multiverse. Through continuous learning and evolution, hybrid intelligence can optimize algorithms, improve models, and improve the accuracy and efficiency of decision making and creation. It can also promote exchanges and cooperation between different universes, share knowledge and experience, and jointly solve complex problems and challenges. This trans cosmic cooperation and innovation will help promote the development and prosperity of the entire multiverse.

## (2) Supervision and Regulation

First, assist and maintain the rules and order. By combining the automation and intelligence characteristics of artificial intelligence and the ethical and moral judgment of human intelligence, a hybrid intelligent system can monitor and identify violations of rules and take corresponding measures to intervene and correct them. This helps ensure that all entities and systems in the multiverse can operate according to the established rules and order and maintain the stability and security of the entire universe. Second, supervise the use and circulation of data. In contrast, data are a valuable resource, and their use and management need to be strictly supervised. A hybrid intelligent system can track the source, flow, and usage of data and ensure that the data are used and shared within the legal scope. This helps prevent data leakage, abuse, and infringement and maintains data security and privacy. Third, promote the realization of fairness and justice. Through smart contracts, decentralized governance, and other technical means, hybrid intelligent systems can ensure fairness and impartiality in resource allocation and power operation. It can prevent individual entities or organizations from abusing power, seeking private interests, and safeguarding public interests and the common values of the entire universe. Fourth, educate and guide to self-management and self-discipline. By providing intelligent guidance and suggestions, hybrid intelligent systems can help entities better understand and abide by the rules of the multiverse and improve their self-management and self-discipline abilities. Simultaneously, it can also guide the entity to develop in a better direction and promote the progress and prosperity of the world by showing excellent behaviors and cases.

## (3) Management and Control

First, optimize and allocate resources through intelligent decision making. Hybrid intelligence plays a crucial role in resource management. Through efficient data processing and analysis capabilities, hybrid intelligence can accurately identify the distribution, quality, and utilization of various resources in a multiverse manner and provide intelligent decision support for resource allocation and scheduling. This helps attain the optimal allocation of resources, improve the efficiency of resource utilization, and avoid resource waste and excessive consumption. Second, intervene and regulate to maintain the stability of the multiverse. Hybrid intelligence plays an important role in maintaining multiverse stability. It can detect potential risks and threats in time by monitoring and predicting various

changes in the multiverse in real time and taking corresponding measures to intervene and regulate. This helps prevent the spread and deterioration of unstable factors in the multiverse and maintains the smooth operation of the whole universe. Third, supervise and manage the implementation of rules and agreements. Hybrid intelligence also plays an important role in rule enforcement and regulation. Through smart contracts, automated monitoring, and other technical means, hybrid intelligence can ensure that all entities and systems in the multiverse comply with established rules and protocols and maintain the order and justice of the entire universe. This will help to prevent violations and ensure the safety and stability of the multiverse. Fourth, promote the synergy, cooperation, and development of different systems. Hybrid intelligence can also promote collaborative cooperation and common developments in the multiverse. Through intelligent coordination and communication mechanisms, hybrid intelligence can promote information sharing, resource complementarity, and cooperative innovation between different entities and systems and achieve the mutual benefit and win-win of the whole universe.

## 6. Conclusions

Hybrid intelligence is the result of the co-evolution of humans and artificial intelligence. The foundation of human intelligence is the human brain represented by biological neural networks, whereas the foundation of artificial intelligence is the mechanical brain represented by artificial neural networks. Human intelligence and artificial intelligence have significant differences and connections in the following six aspects: “information processing”, “knowledge domain”, “learning ability”, “physiological characteristics”, “emotional cognition”, and “moral ethics”. Artificial intelligence has more advantages than humans in solving complex purely intellectual and physical problems, while humans have more advantages in understanding and feeling emotions, morals, and ethics. We need to have a comprehensive understanding of the relationship between humans and artificial intelligence and explore how to combine them to achieve better human–computer collaboration. Design is a purposeful behavior of human-centered creation and planning, and its evolution is directly related to the evolution of human society’s productivity tools. From the perspective of production methods, it has gone through five stages: primary processing in the Hunting Society (Society 1.0), manual artifact in the Agrarian Society (Society 1.0), industrial design in the Industrial Society (Society 2.0), computer-aided design in the Information Society, and computational design in the Super Smart Society (Society 5.0). At the same time, with the advancement of technology, the paradigm of design has also undergone significant changes, mainly including four points: firstly, design tools have evolved from expanding the physical abilities to the brain abilities of designers; secondly, the computer’s response modes to designers has evolved from early passive response to later active generation; thirdly, with the development of digital technology, the output results of design activities can be summarized into two aspects, “materialization of digital things” and “digitization of material things”; fourthly, the iterative optimization of design is undergoing a transition from “static scheme” to “dynamic simulations”; and fifthly, design innovation has indeed shifted from innovation of a single object to systematic innovation.

In the future, design creation activities will be driven by human–computer collaboration based on hybrid intelligence. In terms of thinking patterns, we propose a hybrid intelligent design cognitive model centered on computational design thinking. Computational design thinking combines the design thinking principles of human intelligence with the computational thinking principles of computers to promote creative problem-solving and decision-making processes, thereby enhancing human problem-solving and innovation capabilities. In the design cognitive model driven by hybrid intelligence, human intelligence and artificial intelligence jointly constitute the design information processor, and the external environment exchanges with the information processor in the form of information, material, and energy flow. In the information processor, human intelligence is responsible for inputting design requirements, whereas artificial intelligence is responsible

for editing algorithms based on requirements and producing possible options for requesters to choose from. At the same time, human intelligence sets standards for design quality. Artificial intelligence encodes the standards into parameters, filters the design solutions, and iteratively optimizes them to produce optimized design solutions that meet human commands and requirements.

The rapid development of digital technologies, particularly artificial intelligence (AI), and the emergence of generative AI design tools have enabled humans to shape different spaces. Consequently, this study introduces a multiverse concept, encompassing the “digitalverse”, “natureverse”, and “socialverse”. Within this framework, individuals’ identities are categorized as digital human, natural human, and social human, reflecting their interactions with digital technology, natural ecology, and social renewal. We establish a sustainable development intervention model for human–computer collaboration from a multiverse perspective. This model is positioned to be the core driving force for transforming the digital, natural, and social spaces of human existence in the future. Hybrid intelligence strategies for promoting 17 Sustainable Development Goals are discussed. The role of hybrid intelligence in the development of a sustainable multiverse is reflected in the following three aspects: generation and creation, supervision and regulation, and management and control. The prevailing international metaverse model risks immersing humanity in an incessant quest for the virtual realm, fostering unparalleled prosperity in cyberspace yet causing profound despondency in the physical world. Fundamentally speaking, such a future is unsustainable. And this mode usually only appears in games. In the future, what we need to pay attention to is not only the creation of virtual digital worlds but also the use of digital technology to transform reality to achieve harmonious coexistence with the natural world and a sustainable future. At the same time, we must employ a range of AI-driven technologies to reshape societal relationships, embracing the social nature of humanity and leveraging technological advancements for the welfare of humanity. After all, humans are the creators of technology, and it should remain a tool, serving humanity’s needs, and never supersede the survival, development, and flourishing of our society. Therefore, technological development must align with the principles of sustainable development. The multiverse model represents an evolution of the metaverse, breaking the virtual paradigm and advocating for a future based on technological progress that integrates the natureverse, digitalverse, and socialverse which is far more logical, scientific, and sustainable. This study systematically explores hybrid intelligence-driven design cognitive models and the shaping mechanisms and strategies of a sustainable multiverse, thereby providing important theoretical and practical insights. Since the content of this study is systematic and macroscopic, it is difficult to demonstrate all the theories from a single case. In the future, we will collect as many practical cases as possible to further illustrate the theoretical model, design strategies, and practical methods proposed in this study.

**Author Contributions:** Conceptualization, Y.L.; methodology, Y.L.; software, Y.L.; formal analysis, Y.L.; resources, Y.L.; writing—original draft preparation, Y.L.; writing—review and editing, Y.L.; visualization, Y.L.; supervision, Z.F.; project administration, Z.F. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the China Postdoctoral Science Foundation (grant number: 2023M742017).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** No new data were created.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Varela, F.J.; Thompson, E.; Rosch, E. *The Embodied Mind, Revised Edition: Cognitive Science and Human Experience*; MIT Press: Cambridge, MA, USA, 2017; ISBN 0262335506.
2. Pylyshyn, Z.W. Computation and Cognition: Issues in the Foundations of Cognitive Science. *Behav. Brain Sci.* **1980**, *3*, 111–132. [[CrossRef](#)]
3. Stillings, N.A.; Chase, C.H.; Weisler, S.E.; Feinstein, M.H.; Rissland, E.L. *Cognitive Science: An Introduction*; MIT Press: Cambridge, MA, USA, 1995; ISBN 0262691752.
4. Ball, L.J.; Christensen, B.T. Advancing an Understanding of Design Cognition and Design Metacognition: Progress and Prospects. *Des. Stud.* **2019**, *65*, 35–59. [[CrossRef](#)]
5. Dorst, K. On the Problem of Design Problems–Problem Solving and Design Expertise. *J. Des. Res.* **2004**, *4*, 185–196. [[CrossRef](#)]
6. Bayazit, N. Investigating Design: A Review of Forty Years of Design Research. *Des. Issues* **2004**, *20*, 16–29. [[CrossRef](#)]
7. Roth, G.; Dicke, U. Evolution of the Brain and Intelligence. *Trends Cogn. Sci.* **2005**, *9*, 250–257. [[CrossRef](#)]
8. Henrich, J. *The Secret of Our Success: How Culture Is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter*; Princeton University Press: Princeton, NJ, USA, 2016; ISBN 1400873290.
9. Hughes, R.T.; Zhu, L.; Bednarz, T. Generative Adversarial Networks–Enabled Human–Artificial Intelligence Collaborative Applications for Creative and Design Industries: A Systematic Review of Current Approaches and Trends. *Front. Artif. Intell.* **2021**, *4*, 604234. [[CrossRef](#)]
10. Anantrasrichai, N.; Bull, D. Artificial Intelligence in the Creative Industries: A Review. *Artif. Intell. Rev.* **2022**, *55*, 589–656. [[CrossRef](#)]
11. Dartnall, T. *Artificial Intelligence and Creativity: An Interdisciplinary Approach*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 1994; Volume 17, ISBN 0792330617.
12. Amabile, T.M. Creativity, Artificial Intelligence, and a World of Surprises. *Acad. Manag. Discov.* **2020**, *6*, 351–354.
13. Krinkin, K.; Shichkina, Y.; Ignatyev, A. Co-Evolutionary Hybrid Intelligence Is a Key Concept for the World Intellectualization. *Kybernetes* **2023**, *52*, 2907–2923. [[CrossRef](#)]
14. Kim, S.G.; Yoon, S.M.; Yang, M.; Choi, J.; Akay, H.; Burnell, E. AI for Design: Virtual Design Assistant. *CIRP Ann. Technol.* **2019**, *68*, 141–144. [[CrossRef](#)]
15. Burger, M.; Nitsche, A.M.; Arlinghaus, J. Hybrid Intelligence in Procurement: Disillusionment with AI’s Superiority? *Comput. Ind.* **2023**, *150*, 103946. [[CrossRef](#)]
16. Dellermann, D.; Lipusch, N.; Ebel, P.; Leimeister, J.M. Design Principles for a Hybrid Intelligence Decision Support System for Business Model Validation. *Electron. Mark.* **2019**, *29*, 423–441. [[CrossRef](#)]
17. Kumar, K.; Thakur, G.S.M. Advanced Applications of Neural Networks and Artificial Intelligence: A Review. *Int. J. Inf. Technol. Comput. Sci.* **2012**, *4*, 57. [[CrossRef](#)]
18. Khanam, S.; Tanweer, S.; Khalid, S. Artificial Intelligence Surpassing Human Intelligence: Factual or Hoax. *Comput. J.* **2021**, *64*, 1832–1839. [[CrossRef](#)]
19. Karayiannis, N.; Venetsanopoulos, A.N. *Artificial Neural Networks: Learning Algorithms, Performance Evaluation, and Applications*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 1992; Volume 209, ISBN 0792392973.
20. Shanmuganathan, S. *Artificial Neural Network Modelling: An Introduction*; Springer: Berlin/Heidelberg, Germany, 2016; ISBN 3319284932.
21. Lent, R.; Azevedo, F.A.C.; Andrade-Moraes, C.H.; Pinto, A.V.O. How Many Neurons Do You Have? Some Dogmas of Quantitative Neuroscience under Revision. *Eur. J. Neurosci.* **2012**, *35*, 1–9. [[CrossRef](#)]
22. Levitan, I.B.; Kaczmarek, L.K. *The Neuron: Cell and Molecular Biology*; Oxford University Press: New York, NY, USA, 2015; ISBN 0199773890.
23. Mueller, J.P.; Massaron, L. *Artificial Intelligence for Dummies*; John Wiley & Sons: Hoboken, NJ, USA, 2021; ISBN 1119796784.
24. Winston, P.H. *Artificial Intelligence*; Addison-Wesley Longman Publishing Co., Inc.: Upper Saddle River, NJ, USA, 1992; ISBN 0201533774.
25. Hajkowicz, S.; Karimi, S.; Wark, T.; Chen, C.; Evans, M.; Rens, N.; Dawson, D.; Charlton, A.; Brennan, T.; Moffatt, C. *Artificial Intelligence: Solving Problems, Growing the Economy and Improving Our Quality of Life*; Commonwealth Scientific and Industrial Research Organisation: Canberra, Australia, 2019.
26. Khorasani, E.S. Artificial Intelligence: Structures and Strategies for Complex Problem Solving. *Scalable Comput. Pract. Exp.* **2008**, *9*.
27. Dellermann, D.; Calma, A.; Lipusch, N.; Weber, T.; Weigel, S.; Ebel, P. The Future of Human–AI Collaboration: A Taxonomy of Design Knowledge for Hybrid Intelligence Systems. In Proceedings of the 52nd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 8–11 January 2019; pp. 274–283.
28. Jerbic, B.; Svaco, M.; Suligoj, F.; Sekoranja, B.; Vidakovic, J.; Turkovic, M.; Lekic, M.; Pavlek, B.; Bolfan, B.; Bruketa, D.; et al. Hybrid Intelligence for Visual Identity Design: A Case Study. In *Intelligent Autonomous Systems 17*; IAS-17; Springer: Cham, Switzerland, 2023; Volume 577, pp. 661–670.
29. Jarrahi, M.H.; Lutz, C.; Newlands, G. Artificial Intelligence, Human Intelligence and Hybrid Intelligence Based on Mutual Augmentation. *Big Data Soc.* **2022**, *9*, 1–6. [[CrossRef](#)]
30. Wing, J.M. Computational Thinking. *Commun. ACM* **2006**, *49*, 33–35. [[CrossRef](#)]

31. Wing, J.M. Computational Thinking and Thinking about Computing. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2008**, *366*, 3717–3725. [[CrossRef](#)]
32. Barr, D.; Harrison, J.; Conery, L. Computational Thinking: A Digital Age Skill for Everyone. *Learn. Lead. Technol.* **2011**, *38*, 20–23.
33. Bundy, A. Computational Thinking Is Pervasive. *J. Sci. Pract. Comput.* **2007**, *1*, 67–69.
34. Wang, M.; Wang, Y. A Study on Computer Teaching Based on Computational Thinking. *Int. J. Emerg. Technol. Learn.* **2016**, *11*, 72. [[CrossRef](#)]
35. Wylant, B. Design Thinking and the Experience of Innovation. *Des. Issues* **2008**, *24*, 3–14. [[CrossRef](#)]
36. Panke, S. Design Thinking in Education: Perspectives, Opportunities and Challenges. *Open Educ. Stud.* **2019**, *1*, 281–306. [[CrossRef](#)]
37. Correia, A.; Grover, A.; Schneider, D.; Pimentel, A.P.; Chaves, R.; de Almeida, M.A.; Fonseca, B. Designing for Hybrid Intelligence: A Taxonomy and Survey of Crowd-Machine Interaction. *Appl. Sci.* **2023**, *13*, 2198. [[CrossRef](#)]
38. Wellsandt, S.; Klein, K.; Hribernik, K.; Lewandowski, M.; Bousdekis, A.; Mentzas, G.; Thoben, K.D. Hybrid-Augmented Intelligence in Predictive Maintenance with Digital Intelligent Assistants. *Annu. Rev. Control* **2022**, *53*, 382–390. [[CrossRef](#)]
39. Wu, Y.; Ma, L.S.; Yuan, X.F.; Li, Q.N. Human-Machine Hybrid Intelligence for the Generation of Car Frontal Forms. *Adv. Eng. Inform.* **2023**, *55*, 101906. [[CrossRef](#)]
40. Tsai, T.N. Modeling and Optimization of Stencil Printing Operations: A Comparison Study. *Comput. Ind. Eng.* **2008**, *54*, 374–389. [[CrossRef](#)]
41. Dong, L.; Zheng, H.C.; Li, L.T.; Hao, L.N. Human-Machine Hybrid Prediction Market: A Promising Sales Forecasting Solution for E-Commerce Enterprises. *Electron. Commer. Res. Appl.* **2022**, *56*, 101216. [[CrossRef](#)]
42. Zha, X.F. Toward a soft computing integrated intelligent design framework. In Proceedings of the ICED 09—17th International Conference on Engineering Design, Vol. 6, Design Methods and Tools (pt. 2), Palo Alto, CA, USA, 24–27 August 2009; pp. 439–450.
43. Bahrammirzaee, A.; Ghatari, A.R.; Ahmadi, P.; Madani, K. Hybrid Credit Ranking Intelligent System Using Expert System and Artificial Neural Networks. *Appl. Intell.* **2011**, *34*, 28–46. [[CrossRef](#)]
44. Ostheimer, J.; Chowdhury, S.; Iqbal, S. An Alliance of Humans and Machines for Machine Learning: Hybrid Intelligent Systems and Their Design Principles. *Technol. Soc.* **2021**, *66*, 101647. [[CrossRef](#)]
45. Bu, L.G.; Chen, C.H.; Zhang, G.; Liu, B.F.; Dong, G.J.; Yuan, X. A Hybrid Intelligence Approach for Sustainable Service Innovation of Smart and Connected Product: A Case Study. *Adv. Eng. Inform.* **2020**, *46*, 101163. [[CrossRef](#)]

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.