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Article

Research on Sustainable Design of Smart Cities Based on the Internet of Things and Ecosystems

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Abstract: This paper explores how to improve the sustainability of smart cities from a design perspective, by combining concepts of sustainable design with the Internet of Things and ecosystems. The paper uses a combination of the literature, cases, and model building to develop the research. First, the article analyzes six elements (human, environment, society, economy, and culture) and four dimensions (space, resources, management, and platform) that constitute a sustainable design system for smart cities and constructs a system model based on this analysis; then, the strategy for sustainable design in smart cities is discussed from the perspectives of management and spatial planning by combining CIM and specific cases. The study highlights the importance of prioritizing people and balancing the "people-environment-society-economy-culture" system using technology across the dimensions of management, space, resources, and platform. Moreover, based on the CIM platform, the sustainable design of smart cities can be considered in terms of urban management and spatial planning, enabling people, environment, society, economy, culture, space, resources, and platform to form a smart ecological system and enhance the sustainability of smart cities.

Keywords: smart city; sustainable development; sustainable design; Internet of Things; ecosystems

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1. Introduction

Currently, more than half of the world's population live in cities, a number expected to reach 67% by 2050 [1,2]. Rapid urbanization has led to various environmental, social, and economic challenges [3]. As a result, many people are becoming increasingly concerned, and there is a growing interest in exploring solutions to achieve sustainable urban development [4]. In 2009, IBM introduced the concept of a "smart city"—a vision to use a range of intelligent and informational means to promote development in areas such as urban transportation, medical care, and environmental protection [5]. Since then, building smart cities has been viewed as an effective solution to address the issues faced by cities today [3]. In recent years, many cities in developed countries, such as Amsterdam, Barcelona, Berlin, Cape Town, Copenhagen, Helsinki, London, Milan, Melbourne, and New York, have started to promote smart city development [3,6]. Developing countries, including China, have also seen the construction of smart cities as an essential approach to foster sustainable urban development [6].

Smart cities aim to promote urban sustainability, and an unsustainable city cannot be considered a true smart city [7]. Therefore, ensuring the sustainability of smart cities is of utmost importance. Currently, many scholars have studied this issue from various perspectives using diverse methods. For instance, Zhen Feng et al. (2021) conduct research from a planning perspective, outlining the content of smart city planning and discussing the key focus areas of smart city planning across different spatial scales [8]. Dariusz Gotlib et al. (2020) propose a model and visualization approach to support the development and implementation of transformation strategies in cities, aimed at facilitating the sustainable development of smart cities [9]. Corina M. Rădulescu et al. (2020) use the logic of complex adaptive systems (CAS) to develop a collaborative knowledge network model to study sustainable development in smart cities [10].

Smart city construction is widely believed to enable sustainable urban development [11]. However, there is a growing interest in the issue of the sustainability of smart cities [12]. Nevertheless, there is currently no clear answer available regarding how to achieve sustainability in smart cities. Therefore, this paper explores this issue from a design perspective.

Smart city construction is based on the wide application of information technologies (IT), such as intelligent sensing technologies, the Internet of Things (IoT), and cloud computing [13]. The adoption of IT in smart cities aims to promote sustainable urban development [14]. However, IT alone may not make smart cities sustainable, as technology does not always prioritize sustainability [15]. Therefore, sustainable development can only be realized in smart cities by applying IT technology to sustainable systems. In addition, smart cities also need to collect, transmit, and process real-time data in various fields through information processing systems built on IT technology [13]. Information processing systems for smart cities are mainly based on IoT [13,16,17]. Currently, new smart city construction is primarily realized by building a CIM (City Information Modeling) platform based on the IoT [18,19]. Hence, research on achieving sustainability in smart cities can be approached through the construction of sustainable systems and the application of CIM in smart cities.

Given this, based on the IoT and the ecosystem, combined with a sustainable design concept and CIM, this paper will explore how the sustainability of smart cities can be realized from the design perspective. The research consists of two main parts: first, building a sustainable design system for smart cities by integrating sustainable design concepts with smart cities based on the ecosystem concept; second, analyzing the sustainable design strategies by combining the system architecture of CIM with the smart city sustainable design system. The research approach of this paper is as follows: Firstly, based on the literature review, the paper will explore the content and interrelationship between smart cities and sustainable design, sort out the concepts and scope of CIM, and introduce relevant cases. Secondly, the paper will analyze the construction and implementation strategies of a smart city sustainable design system through the combination of the literature, model construction, and case analysis. Finally, the study will draw conclusions from the research. This study aims to contribute to the sustainable development of smart cities by constructing a theoretical model from a design perspective.

2. Materials and Methods

This section consists of three parts: First, we will review the literature on the concepts and relationship between smart cities and sustainable design. This will serve as a foundation for building a sustainable design system that can be implemented in smart cities. Second, we will leverage the existing literature to clarify the system architecture of CIM and create a conducive environment for applying a sustainable design system to smart cities. Finally, we will introduce relevant case studies to bolster our research on sustainable design systems and strategies for smart cities.

2.1. Smart City and Sustainable Design

(1) Smart city. Bai, O. (2021) et al. state that the smart city is a complex and innovative ecosystem aiming to reshape urban spaces and achieve sustainable urban development through the use of IT [20]. Smart city concepts change rapidly due to rapid IT development. JungHoon Kim (2021) identifies five stages of smart city evolution based on IT development and its application in the literature from 2000 to the present [3]. Mengmeng Wang (2022) et al. state that the IT development level also determines the smart city development level and can facilitate sustainable growth in smart cities [7,21]. Furthermore, in a smart city, intelligence and sustainability are interdependent, with each factor influencing the other [21].

Ahvenniemi et al. (2017) argue that a smart city without sustainability is not really "smart", emphasizing that sustainability should be a part of smart city development [22]. This also means that sustainability is an essential characteristic of smart cities and that the more advanced a smart city is, the more sustainable it should be [23]. The sustainability of smart cities is centered around people and achieved through technological innovation [24]. The purpose of design is also to creatively solve the problems that humans face [25]. Therefore, the goal of the smart city is consistent with the purpose of design.

(2) Sustainable design. Sustainable design is a crucial element of design. The concept of sustainable design is based on the idea of sustainable development, which emerged in the 1980s. It refers to the kind of development that fulfills the needs of the present without compromising the ability of future generations to meet their own needs [26]. The core purpose of sustainable development is to make human development sustainable [27]. Scholars such as Zhiping Song (2022) argue that human sustainable development must include economic [28], social [29], and environmental sustainability [30,31]. However, with the deepening of globalization, sustainable cultural development around the world is facing great difficulties and challenges [32]. Therefore, under the requirements of sustainable development, sustainable design focuses on achieving sustainable development for the economy, society, nature, and culture of humanity. From an ecological perspective, the "human-society-environment-economy-culture" can be understood as an ecosystem. Then, sustainable design needs to adopt an ecological value and view human beings, the economy, society, nature, and culture as a dynamic balance in an ecosystem [33]. The modern concept of sustainable design incorporates design behavior into the "human-environment-society-economy-culture" ecosystem, focusing on this ecosystem and its harmonious development.

(3) The relationship between smart cities and sustainable design. Upon careful analysis of the literature, it is evident that the concept of sustainable design aligns with the sustainable development goals of smart cities, and they share a close internal relationship. Sustainable development requires pursuing economic, social, cultural, and living development while simultaneously preserving the environment [21]. This core value of sustainable design is also an essential requirement for the construction and development of smart cities. Scholars such as Ahvenniemi (2016) and Wendling (2018) have emphasized the need for a balance between humans, economy, environment, society, and culture, forming an ecosystem [22,34]. Ahad et al. (2020) point out that technology, society, economy, culture, humans, and the natural environment all influence the sustainable development of smart cities [35]. Ismaeel Al Ridhawi and Bhagya Nathali Silva, on the other hand, emphasize that following a defined sustainable approach is necessary to achieve all aspects of the smart city ecosystem [36,37]. Therefore, it is clear that smart cities and sustainable design are consistent in their goals and focus on intrinsic content. The intrinsic connection between smart cities and sustainable design is the basis for studying and constructing a system for the sustainable design of smart cities.

2.2. Architecture of CIM

CIM is the foundational platform for the construction of new smart cities. Scholars such as Yali Chen (2022) [38] and Hossein Omrany (2022) [39] have already started to explore the issues related to smart city construction based on CIM. CIM is an organic synthesis based on the IoT, BIM (Building Information Modeling) and GIS (Geographic Information System) [40]. CIM collects and processes the relevant urban data through the IoT, BIM, and GIS, providing comprehensive multi-dimensional management capabilities for the city and fully empowering the planning, construction, management, operation, and service of the smart city.

CIM constructs a 3D digital urban information organic synthesis by building multidimensional information model data and urban sensing data through the IoT, BIM, and CIS [41,42]. Among them, the IoT is an information carrier that intelligently senses, identifies, and manages a range of information of things through various information technologies and devices combined with the Internet, achieving interconnectivity between people, machines, and things [43,44]. BIM is an essential information management tool for urban engineering construction and serves as an information model of buildings, which can achieve integrated and intelligent management of engineering projects from multiple perspectives [41]. GIS is both a digital model of a city and a bearing platform for urban information data. It is an information system that can manage and display data from various aspects of a city through spatial or geographical coordinates [45].

In the CIM architecture, GIS serves as the macro framework for BIM, while BIM complements GIS at a micro level, and the IoT enables the connection between GIS and BIM. The combination of CIS and BIM can involve all aspects of smart cities, while the IoT can realize the interconnection and information exchange of all things. Therefore, CIM collects information through GIS and BIM, and processes it through the IoT. Thus, CIM can be understood as a smart model developed by integrating a range of urban information through CIS, BIM, and the IoT, and is an integrated system of CIM, BIS, and the IoT. CIM is also a digital platform for storing, extracting, updating, and modifying all city-related information [45]. By digitally expressing all-time, all-space, and all-scale information about the city's above-ground, ground-level, and underground areas, past, present, and future, CIM can provide "smart" empowerment for the entire process of urban planning, construction, and operation management [46]. The relationship between CIS, BIM, the IoT, and CIM is shown in Figure 1.

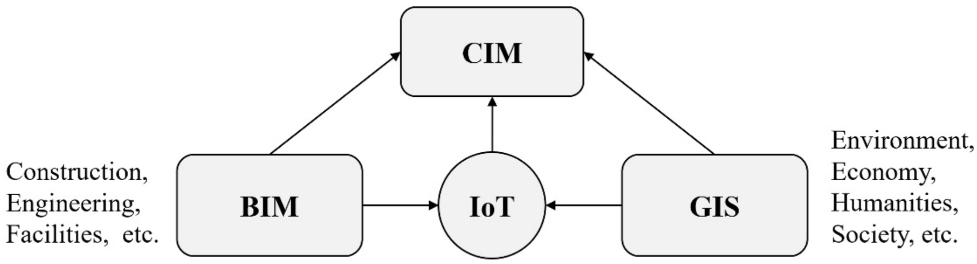

Figure 1. Schematic diagram of the relationship between CIS, BIM, the IoT, and CIM (drawn by the author).

With the support of CIS, BIM, and the IoT, the architecture of CIM consists mainly of four parts: the front-end device, the CIM basic platform, the CIM application layer, and the terminal device.

(1) Front-end. The intelligent front-end includes various types of IoT sensing devices, such as sensors, image capture devices, position-recording devices, actuators, RFID read/write devices, etc. [47]. Through these IoT sensing devices, city infrastructure and environment can be monitored, and IoT data can be collected to provide data support for the CIM platform.

(2) CIM foundation platform. The CIM foundation platform is the carrier of CIM data convergence and application, and it is the fundamental support platform for smart cities. According to the revised "Technical Guidelines for Urban Information Model (CIM) Foundation Platform" issued by the Ministry of Housing and Construction of the Chinese government in May 2021, the CIM foundation platform includes three levels—the facility layer, data layer, and service layer—and two systems frameworks—the standard specification system and the information security and operation and maintenance guarantee system [48]. Among them, the facility layer mainly includes information infrastructure such as 5G, the Internet, the IIoT (industrial IoT), artificial intelligence, cloud computing, and data processing centers. The data layer mainly contains data resources such as space-time foundation, resource survey, planning and control, engineering construction, and IoT perception. The service layer provides functions and services such as data aggregation, management, query, visualization, platform analysis, operation, service, and development interfaces. The standard specification system is mainly aimed at establishing unified standards and specifications to guide the construction and management of the CIM foundation platform. The information security and operation and maintenance guarantee system needs

to be established in accordance with relevant national security policies and standards to guarantee the stable operation of the CIM foundation platform network, data, applications, and services [48].

(3) CIM+ application layer. The CIM+ application layer refers to the application of the CIM basic platform. The content of the CIM+ application layer includes smart healthcare, city management, smart transportation, smart community, spatial planning, etc. [49]. The expanded capability of the CIM+ application can support the planning, construction, management, and decision making of the city [41].

(4) Terminal equipment. The terminal device is the carrier for displaying the services of the CIM platform. Terminals include web browsers, mobile terminal devices, visualization devices, VR/AR, etc. [48]. Certainly, terminal devices not only play a role in displaying content, but also play a specific role in data collection, transmission, and transformation.

Among the four parts of the architecture in CIM, the intelligent front-end is responsible for gathering information; the CIM basic platform handles the transmission, storage, and processing of information; the CIM+ application layer manages and applies information; and the terminal devices output information. Through these four components, the CIM architecture facilitates the construction of a smart city and provides services to users. The users of CIM mainly include government departments, enterprises and business groups, and the general public [49]. The architecture of CIM is shown in Figure 2.

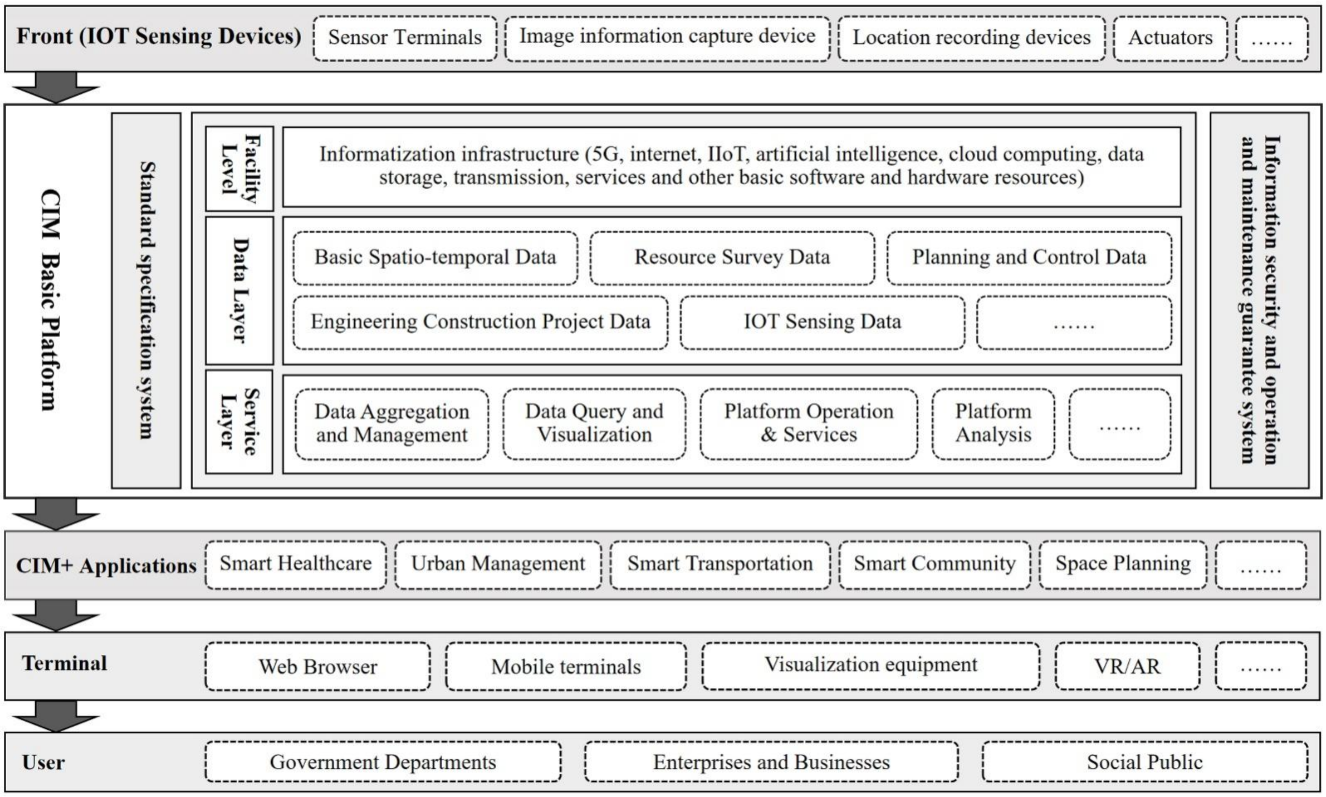

Figure 2. Schematic diagram of the architecture of CIM (drawn by the author).

The powerful functions of CIM can effectively handle various issues in smart city planning and design [39,50]. The application of CIM can facilitate the concrete implementation of sustainable design systems in smart cities. Consequently, the CIM system can serve as a foundation for researching sustainable design strategies in smart cities.

2.3. A Case: Smart City Construction in Suzhou Based on CIM

Suzhou is a city known for its rich historical and cultural heritage and is currently one of the most developed cities in China. In 2022, Suzhou joins various CIM data resources to build the CIM platform for the smart city of Suzhou. The platform includes the CIM foundation platform, CIM spatiotemporal database (including CIM modeling, processing, etc.) and the software part of the CIM+ application system. The CIM basic platform serves as the primary operation platform for urban planning, construction, management, and operation in Suzhou. The CIM spatiotemporal database collects and constructs various CIM spatiotemporal data in Suzhou to create 3D information models and manage various CIM spatial information model data. The CIM+ application system is based on Suzhou's geographic information data and various planning data, and it builds a 3D spatial data model across four modules: planning, construction, management, and operation. It connects with the subsystems of urban planning, construction, management, and operation services to realize the integration and display of a range of information in Suzhou, as well as data indicator analysis.

Moreover, the CIM platform of Suzhou City is built on unified standards and a spatial encoding system. It includes a digital twin spatiotemporal base that is constructed at three different levels: the whole city of Suzhou, the central area, and the historic city area. Each level is developed to meet different spatial ranges and model accuracy requirements. The historical urban area, covering 19.2 square kilometers, serves as the pilot area for constructing the digital twin CIM cockpit system, which includes finely detailed 3D models of both above-ground and underground spaces. Over the years, a live-action three-dimensional model covering approximately 420 square kilometers in the central business district has been built. The platform has also completed the construction of an electronic map, orthophotos, and building models covering the entire city with an area of 8657 square kilometers.

Using CIM, Suzhou has made significant progress in its smart city construction.

Firstly, the government's urban management level gets improved.This has resulted in an overall enhancement of Suzhou City's construction, management, and coordination capabilities. The CIM platform has also facilitated the refined management of Suzhou City's urban planning and construction. It has transformed the approach to urban planning, design, construction, and management, leading to an improvement in the government's scientific management and intelligent decision-making capabilities.

Secondly, the CIM platform has ensured data sharing and circulation among various levels and departments, establishing a data-sharing channel enables 3D spatial-temporal data related to city construction to be shared and jointly built among different applications and departments, thus avoiding duplicate investment in spatial data.

Finally, it has addressed many of the challenges and difficulties in urban management and public services. The CIM platform has effectively integrated various resources, providing comprehensive and diversified services to government departments, transforming the government's service mode and improving the government's public service level.

Suzhou's smart city construction based on CIM has effectively promoted the city's sustainable development from the aspects of city management, city construction and city services. In addition, the application of the CIM platform has fully leveraged Suzhou's unique advantages in the ecological environment, social economy, history and culture. Specifically, this is reflected in the following aspects: Firstly, the establishment of the three-dimensional ecological model of Suzhou's landscape and city focuses on achieving carbon neutrality, simulating ecological balance, and quantifying ecological value. Secondly, it characterizes the characteristics of Suzhou's population, enterprises, and pollution from a broader perspective, promoting an eco-civilization-oriented economic development model and optimizing economic governance. Thirdly, with the protection of the ancient cities as the core, the construction of a digital twin city has been prioritized, reproducing the historical pattern and style of the ancient city of Suzhou.

3. Results and Discussion

This section is mainly divided into two parts: first, based on the relationship between smart city and sustainable design, we construct a sustainable design system for the smart city through the model building; second, based on the CIM system architecture and combining with the case of smart city construction in Suzhou, we discuss sustainable design strategies for the smart cities.

3.1. Smart City's Sustainability Design System

3.1.1. Six Elements of the Sustainability Design System for Smart City

Sustainable design focuses on the harmonious development of the ecosystem composed of the environment, society, economy, and culture with people at the center. Each of these factors plays a vital role in the sustainable development of smart cities. Then, the purpose of smart city sustainable design is to promote the harmonious and sustainable development of the "human-environment-society-economy-culture" ecosystem through design.

In addition, since technology is the foundation of smart city construction and the internal motivation of smart city development [51], sustainable development of smart cities also relies on the intervention of technology. In the sustainable design of smart cities, technology is an important tool and force in the design intervention of the "human-environment-society-economy-culture" system. Therefore, smart cities' sustainable design not only needs to consider factors such as people, environment, society, economy, and culture, but also needs to consider the impact of technology factors.

(1) Human factor. People are the protagonists of smart cities. The main task of smart city construction is to provide people with a comfortable living environment, enabling them to live a happier and more harmonious life, and to adapt to different groups [52]. Therefore, the human factor is the core element to be considered in smart city sustainable design.

(2) Environmental factors. The primary consideration of sustainable design is to reduce environmental pollution, save limited natural resources, create a society that is "resource-conserving" and "environmentally friendly," and promote the harmonious development of human, society, and nature [33]. Therefore, environmental factors are the first and foremost essential elements to be considered in the sustainable design of smart cities.

(3) Social factors. People are the mainstay of society, and sustainable design naturally cannot do without focus on society. The construction of smart cities will also have an impact on people's social activities. Therefore, social factors are also important content elements that need to be considered in the sustainable design of smart cities.

(4) Economic factors. The theory of circular economy and the concept of sustainable development require that sustainable design must be built on the harmonious relationship between social and economic life and cultural life, emphasizing the coordinated development of society and economy. Therefore, sustainable design must seek economic and environmentally friendly ways to address issues in social life [53]. Thus, economic factors are also important elements that need to be considered in smart cities' sustainable design.

(5) Cultural factors. The city is the carrier of culture, while culture is the nucleus of a city [54]. The construction and development of a smart city are influenced by cultural aspects and, in turn, have a profound impact on the development of culture. Therefore, cultural considerations are a crucial aspect of sustainable smart city design.

(6) Technological factors. Technology is the driving force behind smart city development [32] and an essential prerequisite for achieving sustainable growth. Moreover, the application of technology often serves as a means of achieving sustainable design goals. Therefore, technological considerations are an essential component of sustainable smart city design.

In summary, sustainable smart city design requires the consideration of various factors, including human, environmental, social, economic, cultural, and technological aspects. They are, therefore, the essential elements of a sustainable design system. Among them, people are at the core of sustainable smart city design, while technology plays a crucial role in driving sustainable development. Environment, society, economy, and culture are also essential to consider in the sustainable design of smart cities. Sustainable smart city design aims to achieve sustainable development by utilizing technology as a tool to address the interrelated aspects of the "human-environment-society-economy-culture" system. Figure 3 illustrates the six essential elements and their relationships within the sustainable smart city design system.

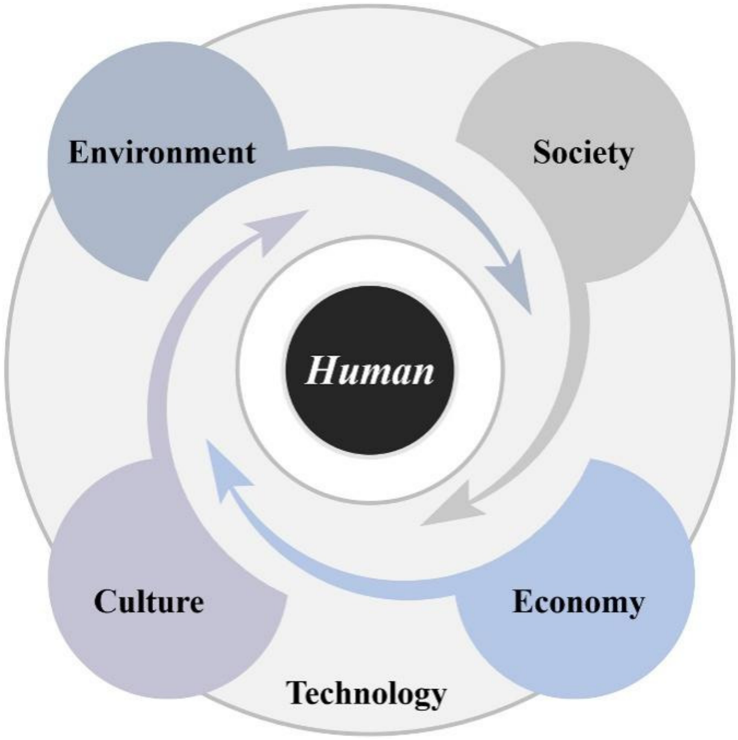

Figure 3. Six elements and their relationships in the sustainable design system of smart cities (drawn by the author).

3.1.2. Four Dimensions of a Sustainable Design System for Smart City

The purpose of sustainable design for smart cities is to intervene in innovation in the construction of smart cities and to consider the sustainability of the "human-environment-society-economy-culture" system of smart cities from the design perspective. In essence, smart cities' sustainable development is to intervene in technology factors into the "human-environment-society-economy-culture" system so that smart cities can achieve sustainable development. The construction and development of smart cities are based on new-generation information technologies such as the IoT and cloud computing, as well as the development and application of tools and methods such as social networks, Fab Lab, Living Lab, and comprehensive integration methods [55]. By combining the latest information technology, big data, network platforms, and smart terminals and fully applying them in various industries and fields of the city, a smart city can be constructed effectively. The sustainable design object of smart cities is embedded in the construction content of smart cities.

Ahad et al. (2020) point out through their research that elements such as management, policy, business, resources, and urban space can affect the realization of sustainable smart cities [35]. The case of Suzhou's smart city construction shows how the development of smart cities can significantly influence a city's "human-environment-society-economy-culture" system. Through smart city development, Suzhou is able to save costs and energy, enhance social services, promote cultural prosperity, and reduce environmental impact, effectively coordinating environmental, social, economic, and cultural factors. Moreover, the application of emerging technologies facilitated information sharing and knowledge diffusion among departments, strengthening the connections between the government, enterprises, and individuals. In the case of Suzhou, smart city construction involves four main dimensions: public spaces, such as communities, offices, and recreational areas; city management, including planning, construction, operation, and supervision; public service platforms, such as technology and network platforms, as well as mobile communication; and public resources, such as infrastructure, policies and regulations, big data, environmental resources, and social resources.

(1) Management dimension. Smart Cities are not only a gathering place for advanced technology but also an important means of achieving social equity through "policy, management and community participation" [56]. The construction of smart cities requires the joint participation of the government, enterprises, and individuals, and requires overall planning, construction, operation, and supervision. Through the management dimension, the contents of the space and resource dimensions can be mobilized, and the operation of smart cities can be realized through the platform dimension, thereby serving society. The management level of smart cities determines the operating costs and development level of society and is the basis for the sustainable development of smart cities.

(2) Space dimension. Urban spaces such as communities, offices, and recreational spaces are the carriers for smart city development. By putting people at the center and utilizing technology, sustainable smart city design can be achieved from a spatial perspective. This can optimize the functional structure of urban space, achieve coordinated development in different regions, and ultimately realize the sustainable development of smart cities.

(3) Resource dimension. Basic infrastructure, policies and regulations, data, and environmental resources are the supporting conditions for the construction of smart cities. Smart city construction not only requires the support of public resources but also needs to guide social equity through rational allocation of resources to achieve sustainable development.

(4) Platform dimension. City public service platforms such as public services, technology platforms, networks, and smart terminals are the embodiment of smart city construction. Smart city construction mainly improves social service efficiency and management level through the application of urban public platforms, thereby promoting the sustainable development of society, environment, economy, and culture. In summary, from the perspective of smart cities, sustainable design for smart cities, based on people and driven by technology, mainly contains management, space, resource, and platform dimensions. The contents and interrelationships of the sustainable design dimensions of smart cities are shown in Figure 4.

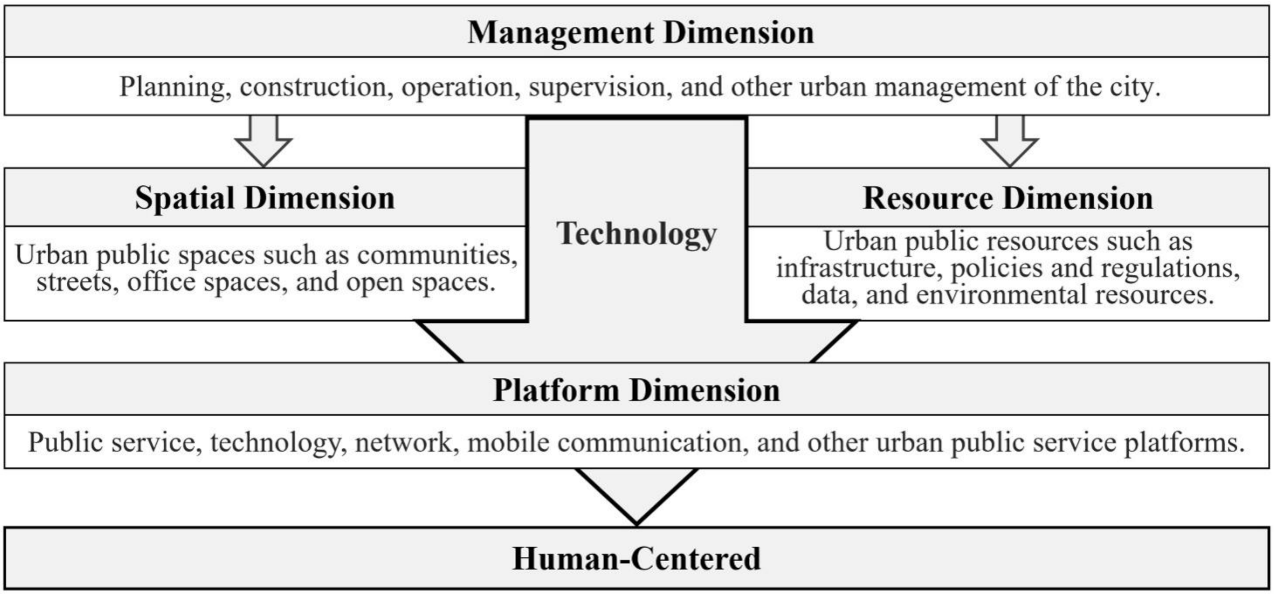

Figure 4. Four dimensions of sustainable design for smart cities and their interrelationships (drawn by the author).

3.1.3. Model for a Sustainable Design System for Smart City

The combination of the six elements and four dimensions of smart city sustainable design constitutes a system for smart city sustainable design. The six elements of smart city sustainable design reflect the requirements of sustainable design for smart cities, while the four dimensions contain the content of the sustainable design. It is clear from this that smart city sustainable design should be centered on humans, using technology to consider the requirements of environmental, social, economic, and cultural factors in the management, space, resources, and platform dimensions. By this, a model of the smart city sustainable design system can be constructed, as shown in Figure 5. The smart city sustainable design system model can serve as a guiding tool for the conceptualization of sustainable design in smart cities, and provide assistance for smart city designers, planners, and managers to think about sustainable development in smart cities.

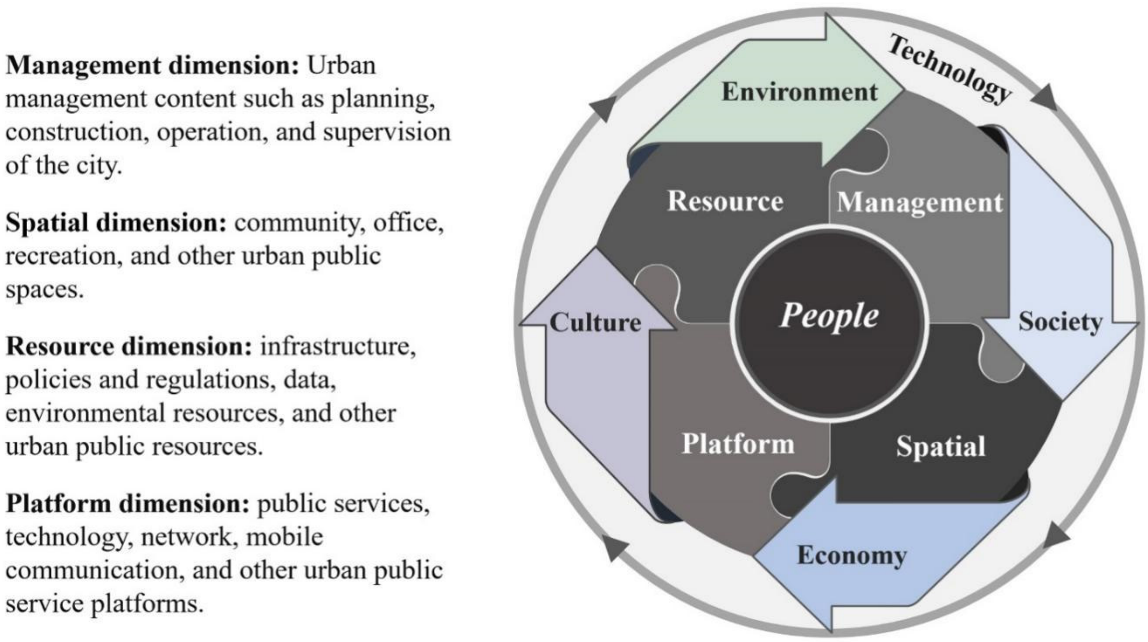

Figure 5. Model of a smart city's sustainability design system (drawn by the author).

The sustainable design system model for smart cities is the visual representation of the smart city's sustainable design system. The elements that make up the smart city sustainable design system include factors such as people, technology, environment, society, economy, culture, as well as content related to management, space, resources, and platforms. Design is the potential factor that brings together all elements of the system. The goal of the intelligent city sustainable design system is to put people at the core, use technological tools to establish connections among all elements, form a system, and finally realize the sustainable development of the smart city.

The smart city sustainable design system model contains four parts: (1) people as the internal core factor; (2) the four dimensions of management, space, resources, and platform; (3) the four influencing factors of environment, society, economy, and culture; and (4) technology as the external driving force factor.

In turn, these four components form three types of interactions with each other: (1) the relationship between people and other parts; (2) the relationship between the dimension component and the influencing factor parts; and (3) the relationship between technology and other parts.

The smart city sustainable design system model can provide some reference for designers in the practice of smart city sustainable design.

3.2. Sustainable Design Strategies for Smart Cities

3.2.1. Management Strategy of a Smart City's Sustainability Design Based on CIM

The main objectives of smart city construction include aspects such as smart economy, people, life, transportation, management, infrastructure, and environment [32,57]. In the construction of smart cities, government departments are not only implementation agencies but also city managers [11]. The case of Suzhou's smart city construction shows that the CIM platform, based on information technology, can be a means and method of smart management.

The CIM platform utilizes intelligent sensing devices (such as cameras, etc.) distributed throughout the city to build an Internet of Things (IoT), enabling all-round monitoring, prediction, and analysis of the city. Through the use of cloud computing and intelligent sensing technology, CIM provides intelligent support for various city elements. By collecting information from the smart city, CIM provides a basis for planning, construction, operation, supervision, and decision making for smart city management. After the completion of the smart city construction in Suzhou, smart city managers can effectively monitor and configure resources, space, and platforms in the city, thus improving the efficiency of city resource and space utilization.

Intelligent city management aims to serve city residents by addressing their daily problems, enhancing the level of urban services, and promoting sustainable development in the city's environment, society, economy, and culture [58]. In Suzhou, the effectiveness of smart city construction is evidenced by the data and information collected by CIM, which mainly come from the resource and spatial dimension. This involves environmental, social, economic, and cultural aspects in smart cities. CIM collects information on geographic, resource, resident, architectural, social, economic, and cultural aspects in smart cities through BIM, GIS system, and IoT sensing devices and then feeds the collected information to smart city managers. With this information, smart city managers can better plan, construct, operate, supervise, and make decisions, leading to the sustainable development of smart cities. The information collection and processing model of CIM is shown in Figure 6.

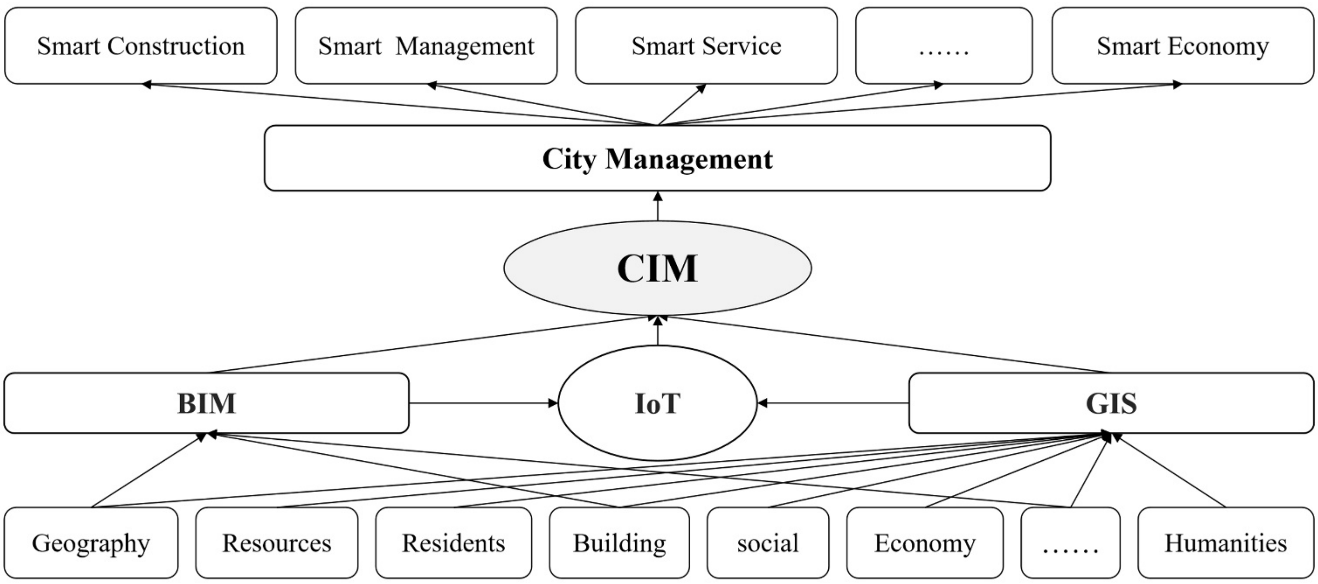

Figure 6. The information collection and processing model of CIM (drawn by the author).

CIM can achieve sustainable development in smart cities by intervening in urban management through a sustainable design system. In the sustainable design system of a smart city, on the one hand, CIM collects data from the resource and spatial dimensions of the city through the platform dimension, as well as information from various aspects such as environmental, social, economic, and cultural factors, providing data to support smart city management. On the other hand, CIM feeds back the planning, design, construction, analysis, and operational decision making of the smart city management dimension to the resource and spatial dimension, coordinating environmental, social, economic, and cultural factors. This enables decision makers to consider sustainable design from a management level. The Suzhou Municipal Government has used the CIM platform to optimize resource allocation from the resource, space, and platform dimensions, providing better services for city residents, reducing environmental pollution, promoting social harmony, and economic and cultural development. The CIM-based sustainable design management model for smart cities is shown in Figure 7.

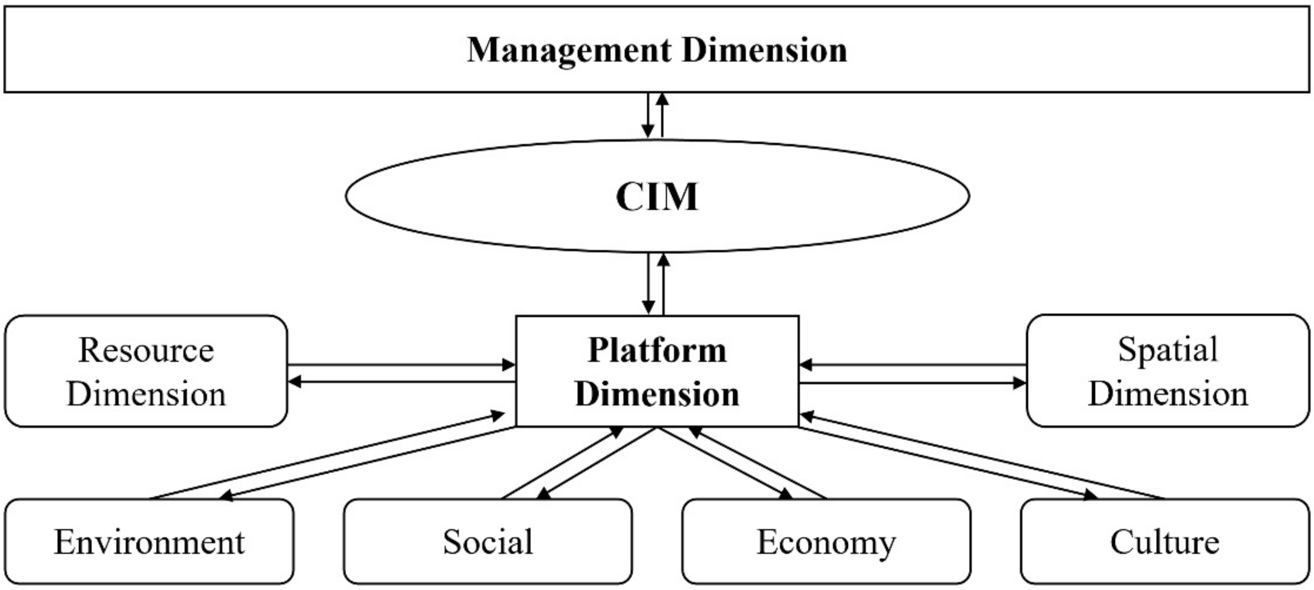

Figure 7. Management model of smart city sustainability design based on CIM (drawn by the author).

The CIM platform enables the integration of people, environment, society, economy, culture, space, resources, and the platform at a management level, forming a comprehensive smart ecosystem. In the case of Suzhou smart city construction, the CIM platform breaks down the data silos of various departments in traditional cities, reducing communication costs and platform duplication [41]. Moreover, CIM can facilitate collaborative relationships among government agencies, supporting the interconnection and collaborative management of information across multiple departments and fields, such as urban planning, design, operation, and management. This leads to a significant improvement in the government's public service capabilities and urban governance models [59]. Suzhou's CIM platform has established a linkage mechanism among 34 municipal-level departments and six district departments. This has resulted in more efficient management of the city's urban management components. These components are divided into five major categories and 128 subcategories, including traffic facilities, city environmental facilities, and landscaping facilities, as well as a total of 90 subcategories of urban management events in six major categories, such as urban environment, advertising, and construction management.

In addition, the CIM platform has the ability to effectively improve the city's environmental ecosystem from the management dimension. Since its implementation, Suzhou City has been utilizing the platform to conduct real-time monitoring of blue-green algae pollution in the city's water bodies on a daily basis. As a result, the efficiency of pollution control has increased by more than 45% equivalent human resource conditions. The utilization of the CIM platform has gradually enhanced Suzhou City's management approach towards the environmental ecosystem, resulting in improved governance efficiency and lowered costs.

With the help of the CIM platform, the city's environmental, social, economic, and cultural resources are integrated, allowing the government to complete its daily work efficiently and quickly. In smart management, the government can leverage the CIM platform to provide better services and living environments for residents, boost the city's economic development, and ultimately achieve sustainable development of a smart city.

3.2.2. Spatial Planning Strategies for Sustainable Design of Smart City Based on CIM

Space plays a crucial role in the design and development of smart cities, and scientific and well-planned spatial strategies are essential for effective smart city management. However, current smart city planning and construction tend to prioritize information technology over spatial planning and integration, resulting in serious issues of duplication of efforts and resource wastage [60].

If we understand a smart city as a person, the management dimension can be compared to the head, while the spatial dimension is like the body. The content of the resource and platform dimensions both rely on the spatial dimension as their foundation. CIM acts as the brain of the smart city management system. By incorporating CIM into the spatial planning of smart cities, issues such as redundant construction during development can be effectively avoided. This allows for the efficient use of resources and space, leading to sustainable urban development. Therefore, to develop sustainable design strategies for smart cities, it is important to consider the spatial dimension in conjunction with spatial planning issues. As smart cities continue to develop, urban space no longer solely refers to the traditional public spaces such as streets, squares, parks, and communities that provide spaces for urban residents' activities. Information technology and network platforms have created many virtual public spaces, while physical space still exists in the city's real environment and is presented to residents as physical entities. Physical space plays a crucial role in urban functions and serves as the foundation for connecting different urban elements [61]. Virtual space, on the other hand, exists online and is presented through intelligent terminal platforms. Although the emergence of virtual space has led to significant changes in people's lives, it cannot replace the role of physical space. In the smart city, physical and virtual space work together to serve residents' lives and influence each other. Physical space is the basis for virtual space, and virtual space supplements physical space. The development of virtual public spaces and technological innovations have both put pressure on and revitalized physical public spaces, injecting new vitality into their development [62].

Traditional urban spatial planning mainly starts from the physical space function and realizes the orderly development of the city through functional zoning of urban space [63,64]. For example, traditional urban spatial planning involves dividing the city into industrial zones, commercial zones, green zones, factories, communities, roads, and parks, etc. Each geographic space unit not only has differences in boundaries but also has corresponding economic and social attributes and exhibits specific functional characteristics and uses [65]. This approach does not account for the fluid and uncertain nature of human activities, leading to significant space and resource waste. The smart city space design, therefore, incorporates natural, geographical, ceremonial, and cultural factors in determining the functional distinction of urban space. Quantitative prediction of the operation of city space is based on population, economy, transportation, water conservancy, and other data and information [66]. So, the spatial planning of smart cities builds upon traditional physical space functional planning and integrates virtual space and information models through intelligent design and construction to realize smart city space design. By starting with the physical space's geographic grid planning and then moving on to the city's virtual space information model planning, intelligent urban space planning can be continually improved. This approach enhances the functional synergy of urban management and services and digital collaboration capabilities, thus contributing to the development of smart cities [67].

CIM can serve as a platform and channel that connects both physical and virtual spaces. After the construction of a smart city in Suzhou, the CIM platform was used to create digital models of various elements in the ancient city area of Suzhou, including buildings, roads, blocks, public facilities, vegetation, water systems, and gardens. Some of the key digital creations were Shantang Street, Pingjiang Road, Humble Administrator's Garden, and Master of the Nets Garden. Using CIM, Suzhou has developed a digital twin ancient city that is visible, tangible, and knowable, and can achieve real-time interaction between people and the digital twin ancient city.

Prior to its physical construction, the smart city space can be simulated using CIM. This process can involve the use of participatory sensing devices and IoT sensing devices; interactive interfaces can be achieved for interaction with people. During this process, a large amount of information is generated, which not only supports urban management but also serves as a basis for spatial planning. The design of the physical layout and functional scenarios of the smart city space requires data intelligence provided by CIM. In Suzhou city, CIM's intervention allows the managers and builders to accurately obtain various information related to urban space. This information helps them understand the needs of infrastructure construction and spatial functionality required in the space and therefore enabling them to plan and construct the smart city space with precision and rationality. The result is digital collaboration in the planning of smart city spaces from functional collaboration. By combining physical infrastructure and virtual information infrastructure related to space, CIM forms the smart infrastructure of urban space, making urban space smart. This allows for the effective use of urban space and reasonable allocation of spatial resources, leading to the sustainable development of smart cities. Figure 8 shows the sustainable design and space planning model for smart cities based on CIM.

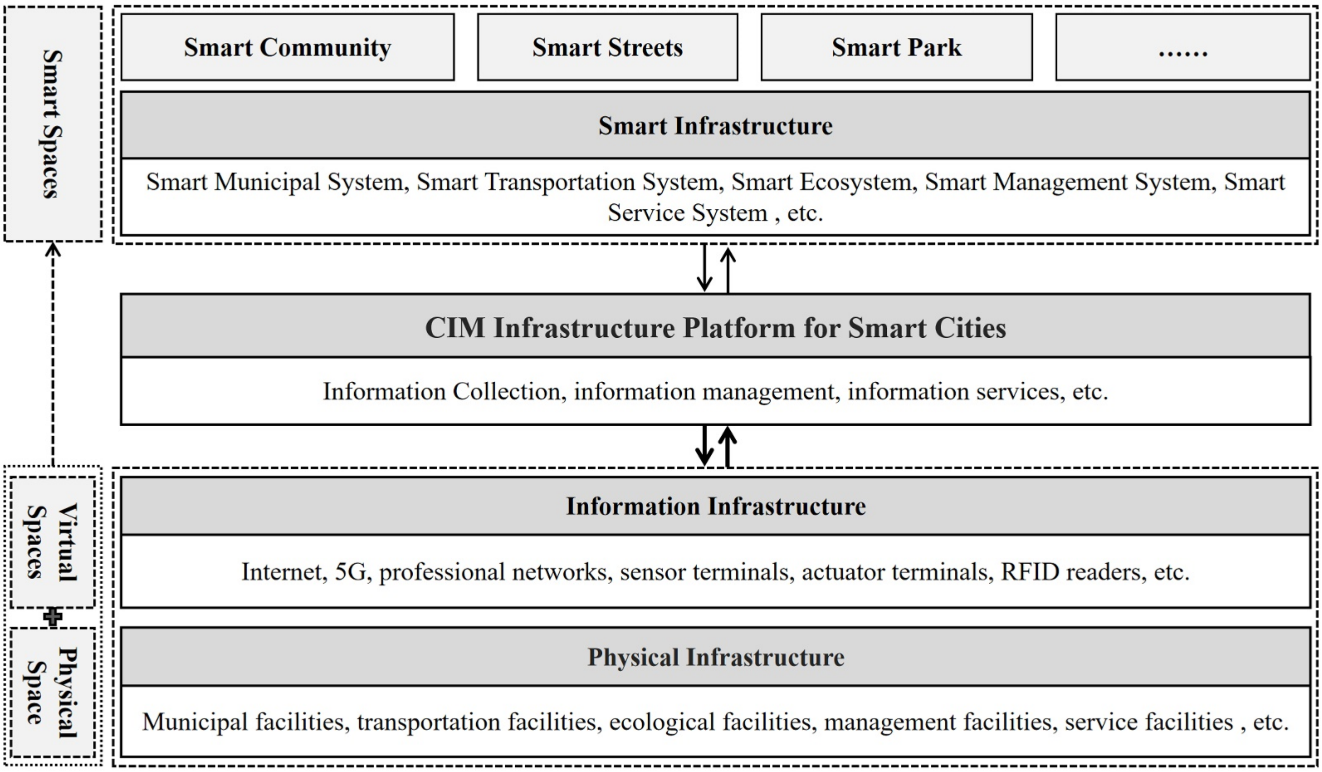

Figure 8. Spatial planning model of smart city's sustainability design based on CIM (author self-drawing).

In summary, CIM can be utilized to acquire and deeply integrate information and data pertaining to people, environment, society, economy, culture, space, resources, and the platform in the smart city space, leading to the planning and design of smart city spaces [68]. Leveraging CIM for planning and designing smart city spaces using the Internet can give city residents a completely different experience in terms of urban space perception, digital visualization maps, and models [69]. By introducing CIM into the spatial planning of smart cities, a balanced ecosystem of "human-environment-society-economy-culture" can be achieved, thereby making smart cities sustainable.

4. Conclusions

This paper takes a comprehensive approach by using the literature, case studies, and model construction based on the Internet of Things and ecological systems to integrate the concept of sustainable design with smart cities. It discusses how to enhance the sustainability of smart cities from a design perspective and examines the relationship between smart cities and sustainable design, the article discusses six elements and four dimensions that make up the smart city sustainable design system and constructing a model of this system. Additionally, this paper explores management and spatial planning strategies for smart city sustainable design using CIM's system architecture as a foundation and in combination with the smart city sustainable design system. Through analysis and research of the smart city sustainable design system and its strategies, the following conclusions can be drawn:

(1) From the perspective of design, constructing a sustainable design system for smart cities can improve their sustainability. The system consists of six elements, namely human, environment, society, economy, culture, and technology, which reflect the requirements for sustainable design of smart cities. The system also has four dimensions, including management, space, resources, and platform, which cover the content of sustainable design for smart cities.

(2) To improve the sustainability of smart cities, a people-centered approach should be adopted in sustainable design, while technology should be utilized to consider the balanced development of the "human-environment-society-economy-culture" ecosystem in the management, space, resources, and platform dimensions.

(3) To improve the sustainability of smart cities, sustainable design can focus on people-oriented management and spatial planning, and through the application of the CIM platform, form an intelligent ecosystem that encompasses people, environment, society, economy, culture, space, resources, and platform.

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