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A Conceptual Blockchain Enhanced Information Model of Product Service Systems Framework for Sustainable Furniture

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Abstract: The sustainable development of the furniture industry is experiencing the challenges of energy consumption and waste disposal. Product–service systems (PSSs) have the potential to promote sustainable development and the opportunity to transition to a circular economy (CE). PSSs can bring a series of benefits to sustainable furniture, but there are still some problems to be considered, such as the safe storage and transmission of information and data and the protection of stakeholders' rights and interests. With digitization becoming a major trend, emerging digital technologies such as blockchain (BC) are proving to have the potential to solve related problems. Therefore, this paper aims to integrate the potential roles of BC and PSSs in the lifecycle of sustainable furniture. This paper adopts a mixed quantitative and qualitative research method. Firstly, the potential relationship among furniture, PSSs, and BC was quantitatively analyzed by VOSviewer. Secondly, this paper qualitatively analyzes the lifecycle stages of sustainable furniture, the advantages of PSSs to promote sustainable furniture, and the potential of BC to enhance the PSSs information model (IM) to further promote sustainable furniture to address related challenges. Subsequently, the conceptual BC-enhanced PSSs IM (BC-PSSs) framework was constructed, which contains the high-level and the low-level of structure and process, and then reviewed and refined through pre-interview questionnaires and follow-up interviews by industry experts and scholars. In addition, discussing the contribution of the conceptual BC-PSSs framework in sustainable furniture, and the potential of BC-PSSs in quantifying design value, encouraging designers to contribute value, and exploring the potential role of BC-PSSs in supporting sustainable consumer behavior. It is the first attempt to construct a conceptual BC-enhanced PSSs IM framework for sustainable furniture from the perspective of lifecycle stages, which can serve as a reference for researchers and policymakers in relevant directions to support sustainable development, in particular contributing to the achievement of SDGs 11 (Sustainable Cities and Communities) and SDGs 12 (Responsible Consumption and Production).

Keywords: product–service systems (PSSs); information model; blockchain; sustainability; furniture; lifecycle management; circular economy (CE); consumer behavior; design

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1. Introduction

With the devastating effects of global warming and resource scarcity, the sustainable development of furniture is receiving increasing attention. Previous studies have shown that the furniture industry accounts for a substantial portion of global trade [1], uses a large number of raw materials, emits exhaust gases, and generates a large amount of waste. Millions of products are produced, consumed, and disposed of every day, leading to resource depletion and waste generation [2]. These unsustainable patterns of production and consumption form the basis of the current linear (acquire-make-waste) economy [3]. From this point of view, the transformation of furniture production and consumption is particularly important for environmental protection and social sustainable development.

Product–service systems (PSSs) have been recognized as "changing production and consumption patterns that may accelerate the shift towards more sustainable practices and societies" [4], and are often outlined as one of the potential enablers for allocating new business models for the circular economy (CE), with the potential to facilitate society's transition to a CE and sustainability [5]. Meanwhile, PSSs can enable sustainable value creation among social, economic, and environmental stakeholders [3]. Currently, the PSSs has been widely used in various fields, such as clothing rental [6], construction [7], and consumer electronics [8], to address growing environmental and sustainability concerns.

In the whole lifecycle of furniture, involving the stages of product design, raw material procurement, and furniture production and distribution, as well as recycling and disposal, it is inevitable to generate a large amount of data and information. These data and information resources are generated by different cross-organizational stakeholders, such as the mutual communication between designers, producers, transporters, and assemblers [7]. Meanwhile, the product itself generates a lot of data and information, such as information about different product components. However, there are some challenges in the process of transforming various types of data into value and ultimately delivering it to stakeholders through various tools [9], and examples include critical data breaches and losses, untraceable logistics, and customer privacy and trust issues [10]. Therefore, it is essential to have an appropriate information model (IM) to guide information collection, sharing, and management [11,12] to ensure secure integration and exchange of information among stakeholders in PSSs lifecycle management.

As digitization becomes a major trend and the role of digital technologies in industry is highly valued, increasing digitization is making possible the vision of a CE of regeneration and recovery [13,14], especially including Industry 4.0 technologies, such as artificial intelligence, big data analytics, cloud computing, Internet of Things (loT), and blockchain (BC) [15,16]. A key goal and feature of Industry 4.0 is to facilitate real-time interconnection between machines, digital devices, transactions, and various stakeholders including suppliers, buyers, and customers [16]. BC technology has the potential to underpin and bring security to the Industry 4.0 vision, which promises to make this possible in a more secure way [13].

BC is considered to have transformative power to change everything from the way business operates to driving the global economy [17], and it has the potential to develop the sustainable furniture industry. Its inherent immutability, transparency, and way of redefining trust relationships by providing fast and secure solutions that can operate publicly or privately have key advantages [18]. Transactions between different stakeholders can be recorded and updated simultaneously and in real time [19]. According to previous studies, BC technology has been widely applied in various fields to cope with various risks, such as processing and protecting patient medical records [20], reducing forged documents and verifying their accuracy [21], and identity management and document authentication in e-government [22].

While both PSSs and BC technologies have been applied to the furniture industry to address related challenges—for example, PSSs have been applied to small furniture manufacturing companies [23], public procurement of refurbished furniture [24], and office furniture manufacturers [25]—BC technology has been applied in furniture mass customization [26], furniture manufacturer value chain [27], and teak supply chain traceability system [28].

However, few studies have established the connection between BC, PSSs IM, and sustainable furniture, and limited literature has applied PSSs and BC technology to the whole lifecycle of furniture to promote its sustainable development. Annarelli et al. (2016) found that only a few studies in the academic literature on PSSs have addressed sustainability as a major theme [29]. Meanwhile, as noted by Mont (2002), there are some fragmented PSSs solutions, but few examples are done on a lifecycle basis [4]. Therefore, this paper aims to integrate the potential roles of BC and PSSs in the lifecycle of sustainable furniture to narrow this limitation. It is the first attempt to construct a conceptual BC-enhanced PSSs IM (BC-PSSs) framework for sustainable furniture from the perspective of lifecycle stages.

The rest of this article is organized as follows: Section 2 introduces the literature review of this article; Section 3 describes the research methods of this paper; Section 4 explores the connection between furniture, PSSs, and BC in the quantitative analysis of the literature. In the qualitative analysis, the lifecycle stages of sustainable furniture in this study are clarified, and the PSSs and BC are integrated into sustainable furniture to solve related challenges. Section 5 establishes a conceptual framework for sustainable furniture based on a BC-enhanced PSSs IM; Section 6 reviews and refines the conceptual framework; Section 7 discusses the contribution of the BC-PSSs conceptual framework in sustainable furniture and the potential of BC-PSSs in promoting the value contribution of designers and promoting sustainable behavior by consumers; Section 8 summarizes this article.

2. Literature Review

2.1. Furniture

Furniture usually contains a wide range of products used in everyday life in domestic and non-domestic spaces for storage, lying, support, sitting, working, hanging, and eating functions. Typical products are desks and tables, chairs, cabinets and closets, beds, and sofas [30]. Furniture is closely related to people's life, study, work, and entertainment. The function, beauty, safety, and comfort of furniture are all needed by people. In most industrialized countries, the furniture industry is a basic industry, accounting for 2% to 4% of the manufacturing output value [30]. According to the latest report by Zion Market Research, the global furniture market was valued at approximately USD 331.21 billion in 2017 and is expected to reach approximately USD 472.3 billion by 2024, growing at a compound annual growth rate (CAGR) of approximately 5.2% between 2018 and 2024 [31].

The furniture industry is essentially an assembly industry, which uses a variety of raw materials to product its products [32]. Therefore, the environmental impact brought by furniture is mainly defined by materials, and previous studies have shown that one-third of all materials extracted from the earth are used in the furniture industry [33]. The main raw material used in furniture is wood, which offers various benefits such as high insulation capacity, renewable resource and fuel, and low weight. Other materials, such as chemicals, plastics, metals, and textiles, are also used in furniture [34]. The furniture industry is one of the markets most affected by consumer behavior [35]. Previous studies have also emphasized the link between user behavior and the durability of furniture products, believing that improper use and excessive use will lead to shorter product life [36]. However, the current trend of consumer behavior seems to be to shorten the service cycle of products, especially the use of furniture in business, as most furniture will not be used before becoming old or damaged, and due to aesthetic reasons and image changes, old furniture will be replaced by new furniture [37]. As a result, the furniture industry has a serious waste problem, which in 2017 amounted to the equivalent of 10.78 million tons of furniture waste per year in the EU-28 countries, accounting for more than 4% of total municipal solid waste (MSW). In addition, 80% to 90% of EU furniture waste in MSW is incinerated or sent to landfills [38]. It is estimated that approximately 12 million pieces of office furniture are disposed of as waste each year in Germany [39]. The linear flow of materials and energy leads to the depletion of natural resources and the generation of large amounts of waste [40].

Throughout the lifecycle, including the purchase of raw materials, manufacturing, and waste disposal, each link transfers matter or energy to the natural environment. According to the 17 UN Sustainable Development Goals (SDGs) [41], the furniture industry violates SDGs 11, Sustainable Cities and Communities (Goal 11 target 6 "by 2030, reduce the adverse per capital environmental impact of cities, including by paying special attention to air quality and municipal and other waste management"). It also violates SDGs 12, responsible consumption and production (Goal 12 target 3 "by 2030, achieve the sustainable management and efficient use of natural resources"). This demonstrates the significance of adopting sustainable practices to reduce the environmental damage and social impact of corporate production [32]. The CE is seen as a significant driver of sustainable development, as it can prevent resource depletion, recycle maintenance materials and products, and recycle potential waste [42]. Therefore, the sustainable development of the furniture industry in the current context is crucial.

2.2. Product–Service Systems (PSSs)

The term PSSs was coined in the late 1990s. Its concept has now been discussed for more than a decade because of its role in sustainable development [3,29,43], and more recently on its contribution to CE [44,45]. As the name suggests, a PSSs consists of three key elements: product (P), service (S), and system (S). In general, products are considered tangible and marketable; Services are intangible activities that are carried out without the need for tangible goods; a system is a collection of products, services, and their relationships [46].

Over the years, different researchers have adopted different terms for the concept of the PSSs. Generally, from the definition of Goedkoop et al. (1999) "a combination of products and services in a system that provides functionality to consumers and reduces environmental impact" [46]. This shows that the initial focus of the PSSs was on environmental sustainability. Currently, Annarelli's latest definition "PSSs is a business model focused on providing a set of marketable products and services aimed at achieving economic, social and environmental sustainability, with the ultimate goal of meeting the needs of our customers" [29]. This definition includes all aspects of sustainability, indicating that the original potential for achieving sustainability through a PSSs is being refocused.

Although researchers have different views on the definition of a PSSs, they mostly adopt the same classification, which divides PSSs into three categories according to the degree of dematerialization [47,48]. (1) Product-oriented PSSs: the transfer of ownership of the physical product to the customer to provide additional services (such as repair and recycling services) for the product to improve the life or utility of the product. (2) Use-oriented PSSs: where the ownership of the physical product is owned by the manufacturer, and the use and functions of the product are provided to the customer. (3) Results-oriented PSSs: Ownership of the physical product is retained by the manufacturer, who provides the result or capability to the customer, a process that involves a substantial system shift in which the physical product is primarily replaced by the service. These strategies can help foster CE and promote sustainable development. For example, product-oriented PSSs can extend the product lifecycle, such as maintenance, and use-oriented PSSs can help companies deal with product use processes, such as leasing [49]. Therefore, a PSSs has the potential to promote sustainable production and consumption and support the transition to CE.

Lifecycle analysis has always been an important topic in PSSs [50]. The lifecycle of a PSSs refers to the whole process from the formation of design concept to the end of use, which involves various information exchanges among many stakeholders. To meet this requirement, providing integrated information management related to products and services throughout the lifecycle is essential [51]. IM has been developed in this area to efficiently collect, exchange, and manage information. For example, using lifecycle information to improve PSSs products and related activities [52], integrating information and data to support PSSs value co-creation [53], and realizing closed-loop lifecycle information sharing in a PSSs [54]. The establishment of PSSs IM has the potential to break vertical information islands in traditional business models [54], coordinate discrete stakeholders [55], and facilitate information exchange at different stages of the life cycle [56].

PSSs lead to a new understanding of the development strategy and value goals of manufacturing enterprises. This business model, whether in a business-to-business (B2B) or business-to-consumer (B2C) environment, integrates products and services to provide value [57]. PSSs are also a potential tool to support social sustainability [58] and the transition to CE by changing companies' incentives to extend the life of their products, thus making them more cost effective and resource efficient [59].

2.3. Blockchain (BC)

Recently, with the continuous emergence of digital technologies, such as BC, cloud computing, big data, and artificial intelligence, as well as the deep integration with various industries, the digital economy has penetrated into every link of economic and social development [60,61]. As a new economic form with digital knowledge and information as key production factors, data privacy, and data security have become the focus of high-quality development of the digital economy [62]. BC technology is suitable for the digital economy in addressing privacy and data security issues and is becoming an important technological foundation for the development of the digital economy [63].

The essence of BC is a series of blocks with records and time stamps, connected by hash values, which has been hailed as foundational [19] and disruptive technology (Jesse, 2018). The key attractive features of BC technology include distributed databases, peer-to-peer transactions, transaction automation, anonymity and transparency, and irreversibility of records.

1. Distributed database. A BC is described as "a distributed database that is agreed upon and shared across peer-to-peer networks" [64]. Each node in the system stores all data, which means that there is no centralized database [65]. This makes the BC a very secure distributed ledger, so all parties have access to the same and correct records and the complete history of the entire database [19,66].
2. Peer-to-peer transaction. BC allows for the sharing of records with all network nodes without central authority; peer-to-peer interconnected ledgers ensure that updates to any one ledger are visible and accessible to all [67]. Decentralization is key to promoting trust and security among interconnected parties, thereby facilitating the digitization of business processes [68]. Through this platform, stakeholders can access the same data and transactions without a single authority and any geographical restrictions [67]. This can enable all components (things) to trade autonomously without the intervention of regulators or brokers [68].
3. Trading automation. BC technology can be used to automate transactions, which can be carried out through digital, automated "Smart contracts" [19,66]. Smart contracts are self-executing snippets of code defined by pre-specified terms that are publicly visible to all nodes on the network or BC, and the smart contract will be triggered when the preset obligations are met [69,70]. Meanwhile, the diversified implementation of smart contracts in different fields is also expected to reduce transaction costs [13].
4. As a repository of transaction lists recorded by forgery-proof documents, BC has the characteristics of application security, reliability, transparency and automation [71]. It is designed to ensure security and use cryptography and distributed consensus mechanisms to provide anonymity, persistence, auditability, resilience and fault tolerance [72]. With its open and transparent nature, BC provides a trusted environment for distributed companies using the Internet for business and transactions, which facilitates record and operations, as well as stakeholder acceptance and satisfaction [67].
5. Irreversibility of records. Security can be further enhanced by using encryption algorithms. All data stored on the BC have a timestamp and asymmetric encryption attached to the BC, which is mainly used to protect ledger consistency and irreversibility of records, ensuring that block data cannot be falsified and tampered with [71]. Once a transaction is updated and verified by all relevant nodes or key parties in the network, it is irreversible and cannot be rewritten or reordered, which ensures data security [65].

In addition, BC has the potential to support the transition to a CE and promote sustainable development. Sustainability and broader social responsibility are achieved through business models that promote circular value creation of decentralized products and services [13]. CE aims to release environmental pressure from economic enhancement and coordinate the relationship between environment, economy, and society [73]. With its composition of open source, peer-to-peer, and distributed ledger systems and automation capabilities, BC has the potential to create cleaner economic transaction processes and help achieve much needed balance and harmony between the environment, economy, and society [13]. BC is seen as a socio-technical or coordination tool that helps connect and coordinate multiple distributed databases [74]. By recording critical data in the BC, long and complex supply chains can be monitored with relative ease and efficiency in the process of products from raw material source to manufacturer to customer [75]. Meanwhile, it can irreversibly update all connected databases and facilitate automation where needed [13]. Therefore, through BC cooperation and knowledge sharing, sustainable development and social responsibility goals can be achieved and CE can be promoted.

3. Research Method

In this paper, a conceptual BC-enhanced PSSs IM framework for sustainable was constructed based on a combination of quantitative and qualitative literature analysis and verified and improved through questionnaires and interviews with industry experts and scholars.

In the quantitative analysis, VOSviewer bibliometrics software was used for analysis, which could reflect the frequency of keywords, the relationship between keywords and the cluster form of keywords by forming the keyword co-occurrence visualization network [76,77]. Therefore, this paper uses VOSviewer software to analyze the relationship between furniture, the PSSs, and BC. In this process, the relationship between the PSSs and furniture sustainability and CE is explored first. Then, in the context of digitization and digital economy, the relationship between BC and the PSSs is discussed. According to the analysis of the previous two, the promise of BC and the PSSs in sustainable furniture is mined.

Qualitative analysis was carried out based on the quantitative analysis results. Firstly, the lifecycle stages of sustainable furniture in this study are determined. Secondly, the PSSs is applied to sustainable furniture and the advantages are analyzed. Then, around the whole lifecycle of sustainable furniture, we summarize the current challenges of sustainable furniture PSSs. Finally, we analyze the advantages that BC brings to the PSSs IM framework and integrate BC into PSSs IM to address the challenges related to sustainable furniture. On the basis of quantitative and qualitative analysis, a conceptual BC-enhanced PSSs IM (BC-PSSs) framework is constructed for sustainable furniture, and BC is used to address the challenges related to the lifecycle of sustainable furniture. The conceptual BC-PSSs framework was reviewed by industry experts and scholars in the "Chinese Society of Industrial and Applied Mathematics BC Technology and Application Summit Forum 2021" (CSIAM-BTAF 2021) [78], which helps to further refine the conceptual BC-PSSs framework. The overall structure of this paper is shown in Figure 1.

The conceptual BC-PSSs framework was validated in the form of pre-interview questionnaires and interviews. SPSS 22 software was used to examine the reliability of quantitative questionnaire data, and NVivo 11 software was used to examine the content of qualitative interview data. To conduct rigorous qualitative research, Lincoln and Guba created reference standards including credibility, reliability, confirmability, and transferability [79,80]. Therefore, the criteria were adjusted according to the research strategy of this paper, as shown in Table 1.

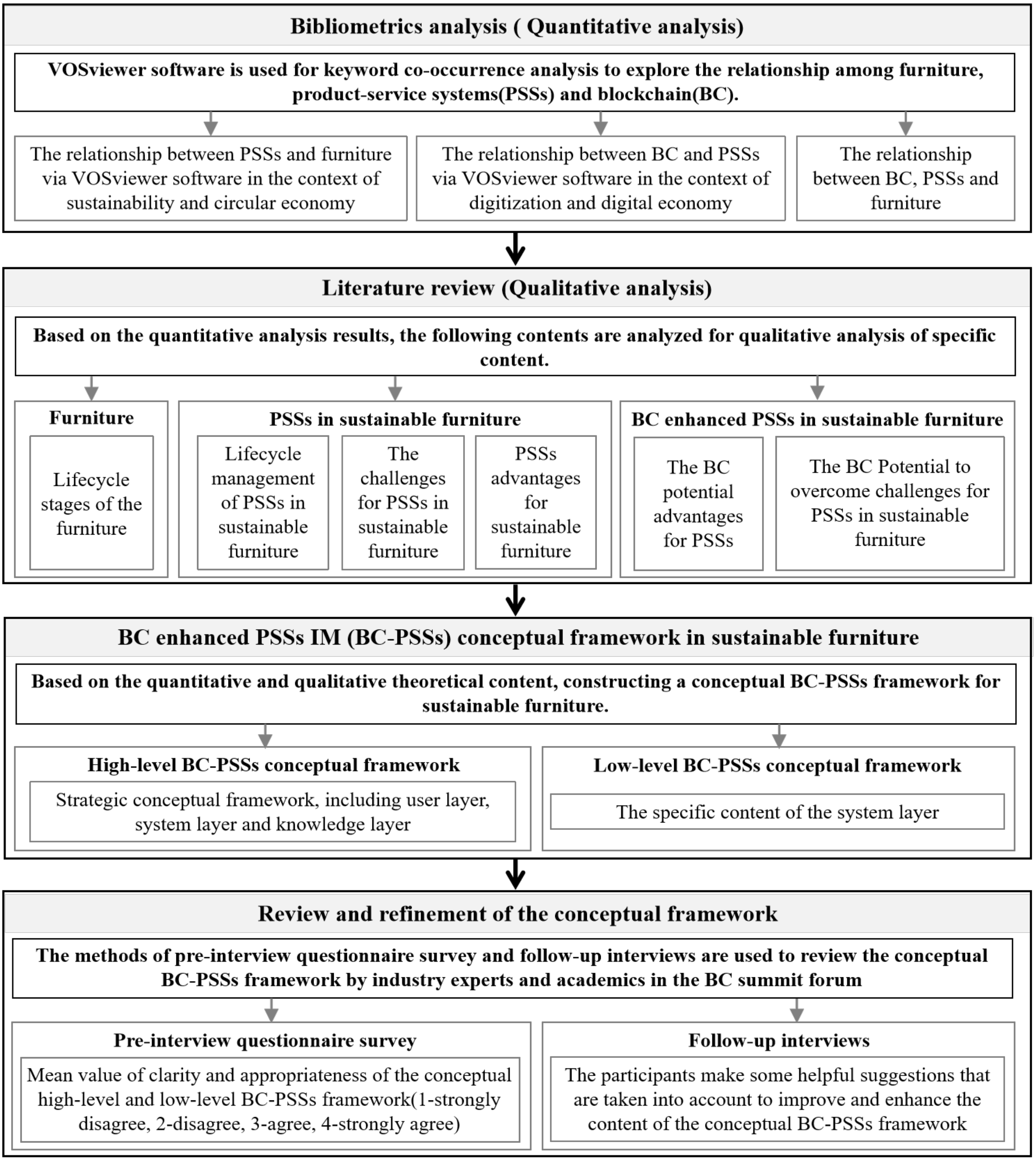

Figure 1. The flow chart of the research methodology (generated by authors).

Table 1. Strategies adapted from Lincoln and Guba applied in this study.

Criteria	Purpose	Strategies Applied in This Study
Credibility	To believe that the results (from the view of the participants) are credible, true, and believable.	Ensure that investigators have the knowledge and research skills required to perform their duties. Ensure all field notes and recordings are stored for analysis.
Dependability	To ensure that the findings of qualitative investigations are reproducible.	A detailed draft study protocol was prepared throughout the study. A detailed track record of the data collection process was developed. Measure the coding accuracy and reliability of the research team.
Confirmability	To establish confidence that the results will be confirmed by other researchers.	Apply multiple techniques (methodology, data sources, investigators, and theory).
Transferability	To extend the degree to which the results can be generalized to other contexts or settings.	Sampling purposefully to form a specified sample. Quantified interview transcripts.

4. Quantitative and Qualitative Analysis

The VOSviewer software was used to analyze the relationship among furniture, the PSSs, and BC. First, we explore the potential of the PSSs to enhance the sustainability of furniture and promote CE. Secondly, in the context of digitalization and digital economy, the link between BC technology and PSSs is discussed. Then, we integrate BC and PSSs to bring the promise of sustainable furniture.

4.1. Quantitative Analysis

4.1.1. Furniture and PSSs

This study aims to understand the current research on furniture and PSSs in developing CE and sustainability and to explore the potential connection between furniture and PSSs. Retrieve TS = (furniture AND circular economy), TS = (furniture AND sustainability), TS = (product–service systems AND circular economy), and TS = (product–service systems AND sustainability) were searched for in the core collection of Web of Science, and 53, 242, 227, and 540 articles were found without the restriction of year, respectively. All the retrieved documents were imported into VOSviewer software for keyword co-occurrence analysis, and the network visualization diagram was generated, as shown in Figure 2. This figure is a visualization of the overall network, which mainly shows the cluster of existing keywords in the search field, as well as the relationship between each keyword. According to Figure 2, the high-frequency keywords (frequency > 100) in this field are mainly "sustainability", "circular economy", "design", "product–service systems", "innovation", and "management ". Meanwhile, in the context of CE and sustainability, the keywords closely related to "furniture" include "wood", "waste", "management", "behavior", "products", and "attitudes"; additionally, "product–service systems" is mainly closely related to "circular economy", "business model", "consumption", "economy", and "environmental sustainability" and "barriers". To further explore the connection between furniture and PSSs, the opportunity to establish the relationship between them is sought in the overall network visualization diagram. Through analysis, it is found that "lifecycle assessment" serves as a bridge to connect "furniture" with "product–service system", as shown in Figure 3 (Figure 3 is the highlighted map of the overall network visualization in Figure 2).

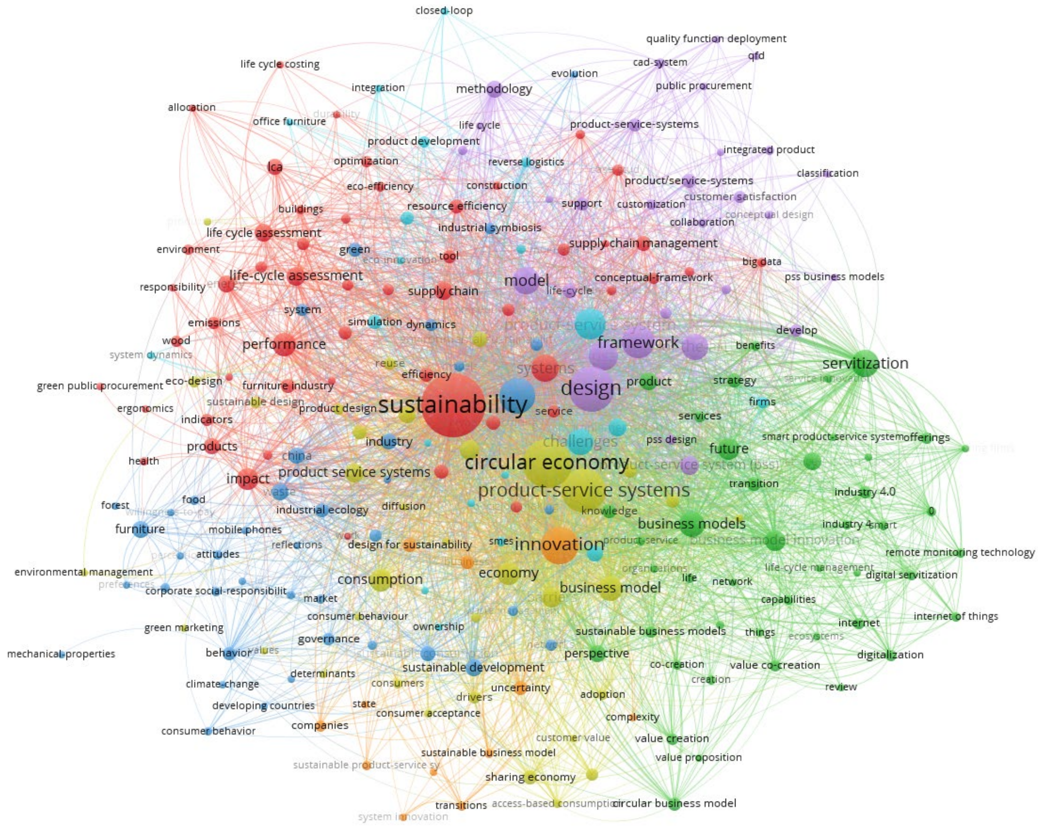

Figure 2. Keywords co-occurrence network visualization of furniture and PSSs in the context of circular economy (CE) and sustainability (generated by authors).

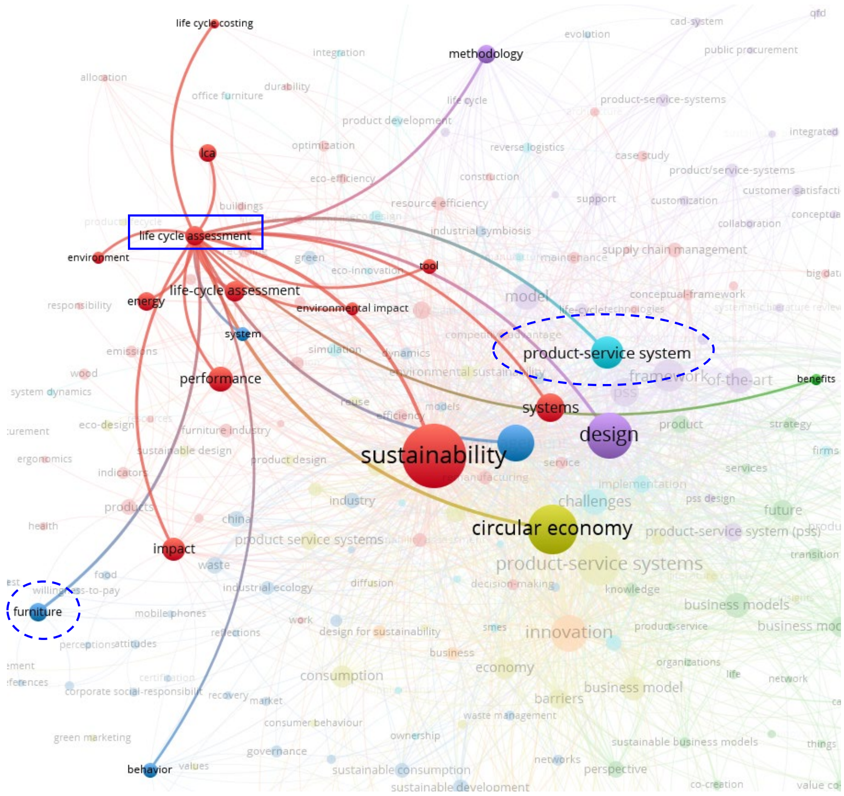

Figure 3. Keywords co-occurrence visualization of furniture and PSSs in the context of CE and sustainability highlighted from the Figure 2 (generated by authors).

4.1.2. PSSs and BC

This study aims to understand the current research of PSSs and BC in the development of digital economy and digitalization to explore the potential connection between PSSs and BC. The authors searched for TS = (product–service systems AND digital economy), TS = (product–service systems AND digitization), TS = (blockchain AND digital economy), and TS = (blockchain AND digitization) in the core of Web of Science, and 40, 43, 272, and 143 were found without the year limit, respectively. All the retrieved documents were imported into VOSviewer software for keyword visualization analysis, and keyword network visualization diagram was obtained. Figure 4 mainly shows the clustering of existing keywords in this retrieval field, as well as the relationship between each keyword. According to Figure 4, the high-frequency keywords (frequency > 35) studied by PSSs and BC in the context of digital economy and digitalization are mainly "blockchain", "digitization", "Internet", "technology", and "blockchain technology". Meanwhile, in the context of the digital economy and digitalization, "blockchain" is mainly closely related to "digital economy", "blockchain technology", "bitcoin", "technology", "big data", "cryptocurrency" and "innovation"; The keywords closely related to "product–service systems" are mainly "servitization", "transition", "digitization", "management", "systems", and "Industry 4.0". According to Figure 5, "digitization" acts as a bridge to connect "blockchain" and "blockchain technology" to "product–service systems".

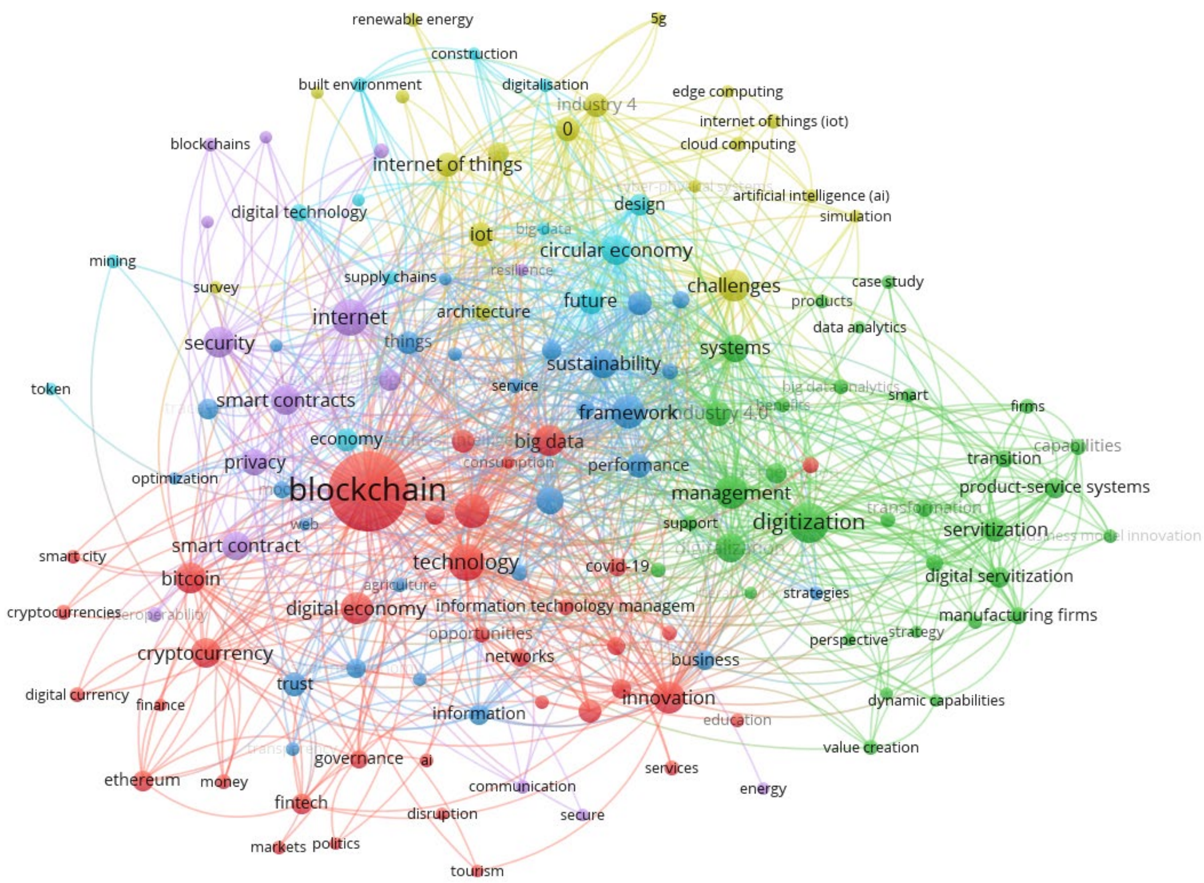

Figure 4. Keywords co-occurrence network visualization of PSSs and BC in the context of digitization and digital economy (generated by authors).

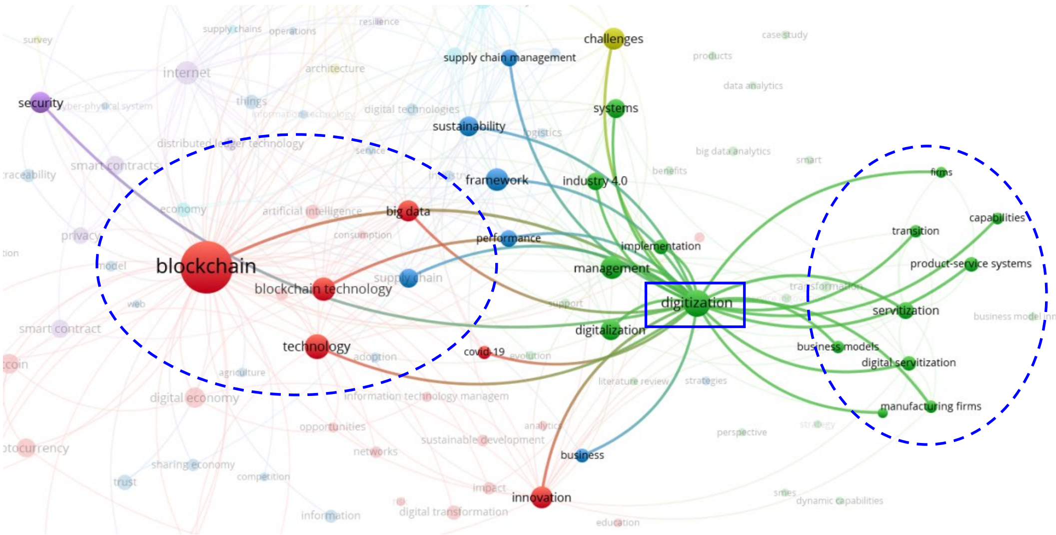

Figure 5. Keywords co-occurrence network visualization of PSSs and BC in the context of digitization and digital economy (detail map) (generated by authors).

4.1.3. Furniture, PSSs, and BC

The relationships between furniture and PSSs and PSSs and BC are discussed, respectively. Further discover the potential promise of PSSs in promoting sustainability and CE in the furniture industry, as well as the potential possibilities of BC in promoting PSSs. This underpins the idea of using BC to enhance PSSs for sustainable furniture in this study. Meanwhile, according to the core collection of Web of Science, research on "furniture AND product–service systems AND blockchain" is still lacking, so this research can fill in the relevant research gaps to some extent.

4.2. Qualitative Analysis

According to the quantitative analysis results of relevant keywords by VOSviewer software, the following research contents are qualitatively analyzed. Firstly, the lifecycle stage of furniture in this study was determined. Then, this study applies PSSs IM to the lifecycle of sustainable furniture, analyzes the advantages of PSSs for sustainable furniture, and summarizes the challenges faced by sustainable furniture PSSs from the perspective of furniture lifecycle. Then, it analyzes the advantages of BC in PSSs IM and uses BC to overcome the challenges faced by PSSs IM in sustainable furniture. It lays a theoretical foundation for constructing the conceptual BC-PSSs framework for sustainable furniture.

4.2.1. The Lifecycle Stage of the Furniture

The lifecycle of a resource usually consists of four successive phases: source, production, use, and end of lifecycle [57]. In a product, the lifecycle can be understood as a series of events that the product goes through, including not only the actual production, but also the services that accompany the whole lifecycle of the product [65]. Meanwhile, environmental impacts run through the entire product lifecycle, from the extraction of natural resources as raw materials, the production process, the use and reuse of products, and finally the disposal stage [81]. According to the product category rules of furniture [82], the lifecycle is divided into upstream stages (processes related to raw materials, manufacturing processes, energy use, and waste generation during production), core stages (processes related to transportation, product assembly/manufacturing, energy consumption, and waste disposal during manufacturing), and downstream phases (processes related to the retailer/distribution platform, transportation, product maintenance, product use, and obsolescence process). In previous studies, researchers have different definitions of the lifecycle stages of furniture based on different research focuses, as shown in Table 2.

Table 2. Previous research related to the definition of furniture lifecycle stages (generated by authors).

Research Focuses	Items	Resources
The process of furniture industry	Raw material supply, manufacture, distribution, use, and disposal	Besch, 2005 [34]
Furniture design assessment	Design stage assessment, production stage assessment, use stage assessment, sales stage assessment, and recovery stage assessment	Chen et al., 2017 [83]
Wood furniture lifecycle	Design, manufacture, manufacture/distribution, use/maintenance, and end of life	Bianco et al., 2021 [82]
Furniture lifecycle (system perspective)	Upstream activities (i.e., production, supply, and processing of materials and components), core activities (i.e., product manufacturing, assembly, finishing, packing, and storage); and downstream activities (i.e., product distribution, retail, use, maintenance, and end of life).	Cordella & Hidalgo, 2016 [30]
The lifecycle of furniture products	Production and supply of materials (P1), product manufacturing (P2), distribution (P3), use and maintenance (P4), and end of life (P5).	Cordella & Hidalgo, 2016 [30]
Furniture lifecycle	Initial investment, design, raw materials, manufacturing, retail/distribution, use/maintenance, and end of life	Bianco et al., 2021 [82]

In this study, the lifecycle stages of sustainable furniture are defined as eight stages, including design, procurement, manufacture, transportation, distribution, maintenance, recycle, and disposal stages, which are described as follows:

1. Design stage: The lifecycle begins with conceptual design, which involves information collection, ideas, design drawings, computer-aided design, innovation, and development of new products, etc. Decisions made at this stage are very important because they have an impact on the whole lifecycle, from manufacturing to the end of life [84]. This is because the binding of product materials and production techniques chosen during the product design phase will determine the pollutants and wastes released and energy consumed during its use, as well as the ease with which its components can be reused in subsequent use and manufacturing cycles [85,86]. It is estimated that 70% of the environmental impacts produced by products are determined at the design stage [87]. Therefore, most of the sustainability characteristics of a product are attributed to the early design phase [88].
2. Procurement stage: Procurement is a prerequisite activity to ensure clear production, which involves inventory management, raw material procurement, etc. The determination of procurement and inventory is very important to minimize inventory costs [89], because the supply of raw materials will affect production and thus sales.
3. Production stage: Production is the process of transforming design concepts into tangible objects. The production of furniture basically includes the assembly of components and the surface treatment of products, which involves the production of component status, production planning, production execution, and production investment to ensure the smooth progress of the production process. The environmental burden at this stage is mainly due to the consumption of electricity and heat energy, but also the consumption caused by the use of painting, drying, adhesives, solvents, and some chemicals [30]. Optimizing resource utilization may be the most effective measure to reduce the environmental impact of furniture production, as significant environmental benefits can be achieved by improving the energy efficiency of the manufacturing process and increasing the use of renewable energy, as well as recycling materials and waste [90].
4. Transportation stage: Transportation delivers products to retailers, which involves container and logistics management, etc. The impact of this stage can be reduced by using more effective transportation methods and optimizing loading and logistics

strategies [90]. For example, giving priority to suppliers close to the furniture production site may be a relevant measure to reduce the environmental burden caused by the transportation process.

5. Distribution stage: distribution sells products to consumers, which involves product display, product transportation, and contract signing.
6. Maintenance stage: The durability and actual use time of the products will greatly affect the impact of furniture products on the environment. Maintenance can extend the lifecycle of a product, and products that are usually easy to clean and dismantle/repair can reduce the environmental impact of this stage. In particular, the effectiveness of any action in this area itself depends on consumer behavior [30].
7. Recycle stage: The option of recovering value from furniture products after their use is widely deployed. Promoting recycling systems can also serve as additional support to the options listed, as well as minimizing the amount of materials and components used in products and promoting the use of easily identifiable and separated recyclable materials and reusable components [91].
8. Disposal stage: Disposal is the end of the life of furniture, which may have a significant impact on the determination of product environmental conditions. The contribution variation at this stage is basically based on the disposal option considered; for example, landfill is the worst disposal option, whereas reuse of products or product components can directly avoid the environmental impacts associated with the production of new units [30].

4.2.2. Lifecycle Management of PSSs Information Model (IM) in Sustainable Furniture

"PSSs is a system of products, services, support networks and infrastructure designed to be competitive and meet customer needs with a lower environmental impact than traditional business models", according to Mont's (2001) overview, a PSSs means not only the services and products delivered, but also the infrastructure and networks that facilitate the system [92]. This fact supports the claim that PSSs development requires interactions across the entire product chain [93]. Therefore, a broad view of the product–service lifecycle is critical to achieving good PSSs performance.

The PSSs aims to maximize the use of the product and its maintenance, prioritizing system administration throughout the product lifecycle [43]. According to the research [34], the establishment of a PSSs needs to include three important roles, namely the manufacturer, retailer, and consumer. Manufacturers are groups that focus on the design, production, and re-manufacturing of furniture; the retailer is the link between the manufacturer and the customer. Many furniture manufacturers sell their products through the retailer, and the customer buys the products through the retailer and signs the full service contract with the retailer. Given the key role of consumers in CE [45], in addition to production and distribution, the whole circular supply chain should also consider the consumption process; particularly, the level of consumer awareness of environmental and sustainability issues may greatly influence the practical implementation of circular business models [94].

Based on the above overview, PSSs IM is defined in this paper. Firstly, according to the three important roles of manufacturer, retailer, and consumer in the PSSs proposed by Besch (2005), this paper defines the manufacturer as the manufacturing group of products, the retailer as the distribution group, and the consumer as the consumption group [34]. Meanwhile, according to Section 2.2 of this paper and the three key elements of product, service, and system in the PSSs, in this paper, the product corresponds to the manufacturing group, the service corresponds to the consumer group, and the retailer is the link between the product and service, reflecting the transmission of product to service, and finally forming a complete system combining product and service. This is shown in Figure 6.

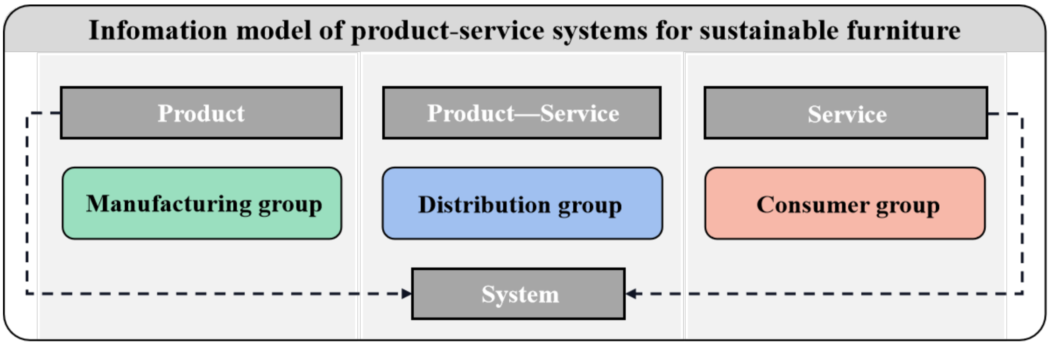

Figure 6. The composition of the product–service systems (PSSs) information model (IM) in this study (generated by authors).

According to the lifecycle stage of sustainable furniture, the specific embodiment of PSSs IM applied to sustainable furniture is shown in Figure 7. "Product" in the PSSs corresponding to the "design stage", "procurement stage", and "manufacture stage" of sustainable furniture belongs to "manufacturing groups". The "transportation stage" and "distraction stage" of sustainable furniture correspond to the "product–service" in the PSSs, which are "distraction groups". The "maintenance stage", "recycle stage", and "disposal stage" of sustainable furniture correspond to "service" in the PSSs, which belongs to "consumer groups". Finally, the whole lifecycle of sustainable furniture forms a system that combines products and services.

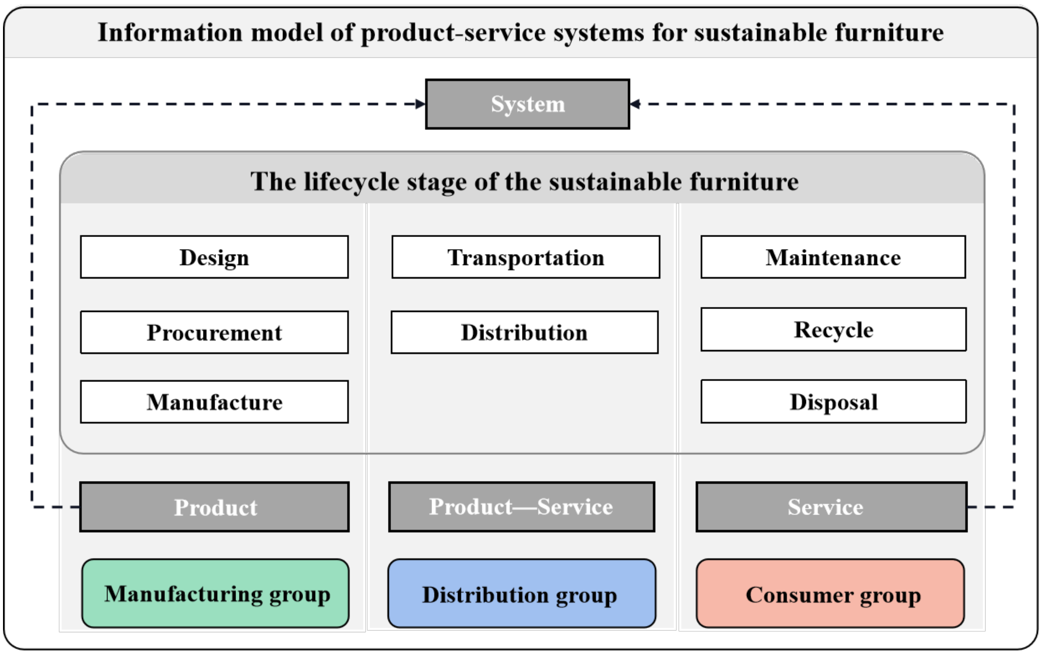

Figure 7. Sustainable furniture PSSs IM in this study (generated by authors).

According to the potential of a PSSs in facilitating stakeholder assistance and enhancing lifecycle knowledge management, in this paper, PSSs is used for the stakeholders and lifecycle stages of sustainable furniture to play its potential role. Figure 8 illustrates the ability of PSSs IM to enhance sustainable furniture. With the introduction of PSSs, the coordination and communication between the key stakeholders in sustainable furniture such as designers, suppliers, engineers, and producers is further enhanced. At the same time, the sustainable furniture lifecycle phase closes the material and energy flow, reduces the exploitation of natural resources, and reduces waste generation, and the material resources in the end of the lifecycle process will be re-channeled to the beginning of the next product lifecycle. Various information from stakeholders and lifecycle stages flow with the support of the PSSs, facilitating coordination and improving collaboration and communication, while lifecycle knowledge management is carried out to validate, manage, and share all information assets of the organization, such as databases, documents, and organizational policies and procedures, as well as to potentially harvest the tacit skills and experience of knowledge workers. In addition, the PSSs embodies the core concept of CE "reduce, reuse, and recycle" throughout the lifecycle of sustainable furniture, in line with the goal of a CE to break away from the linear approach of "make, use, dispose" and promote the sustainable development of the furniture industry.

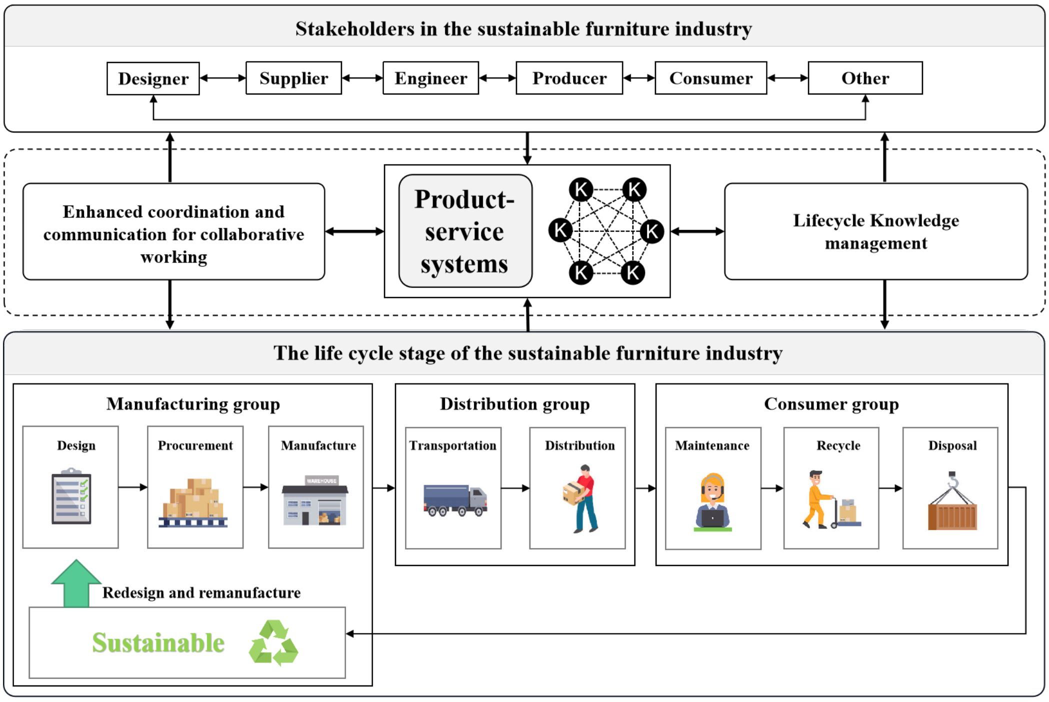

Figure 8. The lifecycle of sustainable furniture enhanced by PSSs IM (generated by authors).

4.2.3. PSSs Advantages for Sustainable Furniture

The economic and ecological potential of the PSSs lies in the area of optimization of the whole system, extending from a single product lifecycle to an integrated product–service lifecycle [49,95]. From a systems point of view, products are designed not only to provide innovative learning environments that meet current needs, but also to support the sustainable development of society through sustainable production and consumption and CE. In other words, the PSSs is not only a collection of products, services, and other elements, but also includes the value proposition, the type of interaction between stakeholders, and the solution to social problems [3]. Systematic lifecycle management of PSSs brings the following benefits to sustainable furniture.

1. Lifecycle knowledge management. Knowledge management is the organizational and technical basis for enterprises to promote knowledge sharing and reuse [96]. PSSs can reasonably and effectively manage the products, services, data, and information generated in the whole lifecycle, and provide the required knowledge to different stakeholders in each lifecycle stage [97].
2. Forming a closed loop of materials. The PSSs minimizes the impact of consumption on the environment by closing the material cycle, including the return of furniture from the customer to the manufacturer, in which case furniture elements can be remanufactured, updated, and reused [34]. One can get the most out of the product and its maintenance through lifecycle system management.

3. Promote collaboration among stakeholders. The PSSs enables networked stakeholders in the product value chain to collaborate effectively [7]. These centers are based on strategic partnerships between manufacturers and suppliers, customers, supporting institutions, and other stakeholders to promote the development of a culture of value-added products in the furniture industry [98].
4. Improve the competitiveness of enterprises. The PSSs can strengthen the relationship between enterprises and consumers, and the construction of this relationship promotes the loyalty among consumers [99]. In addition, companies can use the information gained from consumer relationships to develop new systems to improve product performance [100]. Companies can improve their position in the value chain and increase their innovation potential [101].
5. Increase resource productivity. Servitization offers access to a functional dematerialized future that is possible in the long run, as well as opportunities to increase resource productivity in the short run [48]. Increased service supply compensates for job losses due to cutbacks in traditional manufacturing and relieves consumers of responsibility for services, such as installation and maintenance, as well as product disposal at the end of their useful lives [43].

4.2.4. The Challenges for PSSs in Sustainable Furniture

Although PSSs have great advantages in the lifecycle of sustainable furniture, there are still some challenges that cannot be solved. The following are eight major challenges to sustainable furniture PSSs from a lifecycle perspective.

1. The intellectual property rights of creators cannot be protected. One of the characteristics of product design is the interdisciplinary nature of the design process, which means that designers may work with material engineers, structural engineers, and other professionals [102]. The results of these professionals' work together promote the development of new products. However, with the transfer of work results, the knowledge transfer becomes difficult to track, and the legal rights of the knowledge contributors cannot be ensured. At the same time, unauthorized copying, "stealing", and other infringement methods have become common scenes, which also seriously damage the rights of original creators [103]. Existing central website-based copyright management where the content is inaccurate, easy to attack, without strict and credible traceability, and other shortcomings need to be addressed [71].
2. Improper inventory management of raw material procurement This includes lack of trust and transparency among key stakeholders in the procurement process, weak system support for transaction records and documentation, and complex process structures [104]. Due to the improper delivery of raw materials by suppliers, the shortage or unavailability of raw materials occurs from time to time. This will lead to serious consequences: First of all, the distribution of raw materials is delayed and the production schedule will be disrupted, which leads to delays in receiving the goods by customers, which affects consumer satisfaction. Secondly, prompting enterprises to rush to order from other suppliers, the result of urgent orders is the emergence of additional costs for companies [105].
3. Product elements lack standardized specifications and production principles. Due to the lack of a standardized production system, the production process is characterized by low production efficiency and long and unstable production cycles. Furniture products include different manufacturing materials, different colors and specifications, a large number of various types of parts, large differences in process production, and lack of standardized specifications and production principles, which will cause management difficulties and affect delivery [106].
4. Lack of logistics planning and low transport efficiency. Efficiency, speed, and agility in transportation operations are essential elements that make up the furniture manufacturers of the future. However, even if different furniture companies located in the same area ship to the same market area, the same city, and/or the same furniture

retailer, coordination of transportation operations between two or more companies is rare [107]. One reason for the inefficiency is that most trucks return to the plant empty. The environmental impact caused by product transportation is the main environmental burden of the office furniture industry [108].

5. Product distribution brings distrust to consumers. More and more consumers are aware of environmental concerns and therefore tend to buy sustainable products. However, certain green advertisements present a mixture of facts, ambiguous information, and provide misleading and exaggerated information about the green benefits or environmental or health attributes of the product [109]. These lack of credibility advertisements hinder consumers' trust in green furniture and give users a poor or even unbearable experience. Some consumers are skeptical of eco-labeled products, have a lack of trust in the products being sold, and have a genuine commitment to trust attributes that may reduce consumers' purchase intention [110]. In addition to this, certain low-quality ads may contain viruses that induce users to click and then steal private data [111].
6. Maintenance service cannot be effectively guaranteed. On average, consumers buy new furniture every three years. The main reason for consumers to buy new furniture is the need to replace worn or damaged furniture [101]. The biggest problem found after three years of use of furniture is the wear of parts, material deterioration, and furniture companies that do not support repairs and do not provide spare parts services to customers. As a result, accumulated end-of-life products are discarded and difficult to manage, eliminate, and destroy [112].
7. Lack of a complete recycling system. Most waste furniture is burned or buried [113], resources are not effectively utilized, and even the environment is affected by waste treatment means [114].
8. Lack of secure data storage and transmission. The furniture lifecycle includes multiple stages, and various data are gradually detailed through each stage; as a result, there are a large amount of data. Various data and knowledge resources are held by different cross-organizational stakeholders, such as manufacturers with status data and detailed design, manufacturing and reliability knowledge, service providers with maintenance data and experience knowledge, and consumers with usage data for systems [115]. Nevertheless, the PSSs can facilitate the collection, management, and sharing of resources. However, it is difficult to ensure the security and privacy of shared knowledge, and the loss and destruction of data can greatly reduce the effective transmission of information.

4.2.5. The BC Potential Advantages for PSSs IM

According to Section 4.1.2, there is a potential connection between BC and PSSs. Through the relevant literature, it is found that BC has potential advantages in PSSs IM. The PSSs is seen as a novel business model that focuses on cost, convenience, CE, and the environment [116], and it is able to improve value creation by improving circularity [117]. The value creation part of the business model is used in scenarios where products or services are provided to customers. However, in order to reasonably and effectively manage the products, services, information, and data generated throughout the lifecycle of a PSSs when providing services throughout the lifecycle of a product, consideration needs to be given to how to securely track and trace products, how to trigger services, and how services are delivered, and the problem of data insecurity and low trust among stakeholders must also be overcome [65].

BC can help stakeholders in PSSs store data in a more secure way, enabling decentralized peer-to-peer transactions that are anonymous and visible to everyone in the chain [65]. This provides strong support for later data utilization and service innovation, providing new ways to improve traceability and transparency throughout the product lifecycle [118]. Specifically, the lifecycle of PSSs refers to the entire process of PSSs from the formation of the design concept to the final use, which contains a number of different stages, and the BC can improve the traditional PSSs lifecycle management from multiple aspects [97]. For example, in the creative and design phases, BC enables companies to apply recommendation algorithms, where manufacturers can get accurate recommendations without the customer revealing his/her data; during the implementation phase of products and services, the potential benefits of BC include trust among stakeholders, greater supply chain efficiency, and customer satisfaction. In the use stage of the product, the BC helps the PSSs improve the maintenance and upgrade service, and the irreversibility of the record ensures the efficient and error-free verification of the service results in the PSSs and realizes safe and efficient resource sharing.

4.2.6. The BC Potential to Overcome Challenges for PSSs IM in Sustainable Furniture

BC has the potential to facilitate the implementation of PSSs IM in sustainable furniture. In addressing the eight identified challenges of sustainable furniture, BC has the following potential roles to play:

1. Protection of the intellectual property rights of creators. The timestamp and asymmetric encryption features of BC technology ensure that block data cannot be forged and tampered with. For each copyright transaction, such as authorization, distribution, tracking, use, and destruction, the copyright owner will form a unique sub-chain according to time [71]. BC can more securely share expertise and/or business performance data owned by brand/franchise owners, while distributed storage provides transparency and openness to the BC as long as the person registered in the BC is able to know the ownership of the work and other relevant information, thus avoiding the leakage of business-sensitive information, customer records, and patented technology to "third parties" and/or cybercriminals [119].
2. Effective inventory management of raw material procurement. BC can contribute to more accurate demand forecasts when planning inventory purchases, not only gaining a cost advantage, but also eliminating unnecessary waste of resources [120]. By integrating BC into furniture PSSs, it can help control and track materials to reduce the likelihood of overstock, defective, and/or illegal inventory [121].
3. Improving the standardization and production of product elements. More accurate forecasting of material requirements in the production process reduces the frequency of material expiry due to excess inventory [122]. Each stage of subcontracting takes the form of smart contracts in BC that can be converted into programs and code, which are then copied and stored in a processing system and monitored by a network of systems running the BC [7]. Therefore, the bill of quantities of product elements (PC) can be obtained, and classified management, accurate control of inventory supply and demand, flexible adjustment of PC output, and continuous production capacity of PC can be ensured.
4. Effectively implement logistics planning and transportation management. At this stage, BC can be used to prevent security breaches while enhancing transport connectivity and delivery services. Transport is a key player in connecting supply and distribution and enabling a transparent, sustainable, and efficient flow of status data between them [7]. After receiving the order, the delivery plan and driver allocation can be carried out automatically, and the entire transportation phase is also monitored in real time. At the same time, the BC can also store information and images (e.g., component status, driver information, routes), and if an inappropriate operation occurs, the cause and responsible person of such problems can be immediately tracked through the system.
5. Improving consumer trust in the distribution process. The use of BC technology has improved the quality and effectiveness of advertising, increased the enthusiasm and experience of users, and improved the adverse impact of the proliferation of low-quality advertising on users [111]. At the same time, BC as a transparent, distributed. and clean register, as well as the use of QR code based on BC technology in the product, can let consumers understand the product source, manufacturer name, and packaging

date, which plays an important role in promoting the traceability of furniture products, facilitating query and not copying [71].

6. Improving maintenance services and contract effectiveness. Maintenance and upgrades of the product are especially important because they extend the life of the product and can provide continuous service. With the help of BC, maintenance agencies can create smart contracts based on maintenance standards for different products and submit smart contracts to the BC [97]. When the user submits the information to meet the terms of the smart contract, the maintenance agency can provide repair suggestions or services in a timely manner or even in advance.
7. Improving the waste recycling and treatment system. BC can help recyclers verify the status of recycled products and carry out waste tracking and management. BC creates a more efficient and transparent system that helps track waste [123], and waste tracking ensures that recyclables do not appear in landfills [124]. After being properly repaired, waste furniture can be re-marketed as a product, reducing the environmental load [113]. The entire process can be recorded on the BC, and intermediate transactions are done through smart contracts, helping to achieve an efficient and transparent recycling process, enhancing user trust, and promoting sustainable development.
8. Ensuring secure storage and efficient transmission of data. The database must maintain data integrity in order to truthfully inform shareholders about progress and any existing issues or obstacles [7]. The use of BC to strictly encrypt the data in sustainable furniture to ensure authenticity not only enhances the value of data sharing in the lifecycle, but also improves the anti-risk ability of PSSs.

According to the above, BC has the potential to facilitate the implementation of PSSs IM in sustainable furniture and solve lifecycle-related challenges, digitally driving the entire lifecycle of sustainable furniture. As shown in Figure 9, the advantages of integrating BC and PSSs IM and applying them to stakeholders and throughout the lifecycle to play a potential role: First, among stakeholders, BC enhances PSSs IM and promotes coordinated trust among stakeholders in sustainable furniture. Secondly, in the lifecycle, BC-enhanced PSSs IM strengthens the links between the various stages of the sustainable furniture lifecycle and solves the associated challenges. BC then enhances the lifecycle knowledge management of sustainable furniture PSSs IM for reviewing and managing knowledge related to different domains to verify, manage, and share all of an organization's information assets such as products, documents, organizational policies, and procedures. Meanwhile, in the whole process, a full lifecycle information database is established with the support of BC, and the information system allows for dynamic marketing communication between enterprise product management, distribution channels, and direct sales personnel, as well as securely storing and transmitting data.

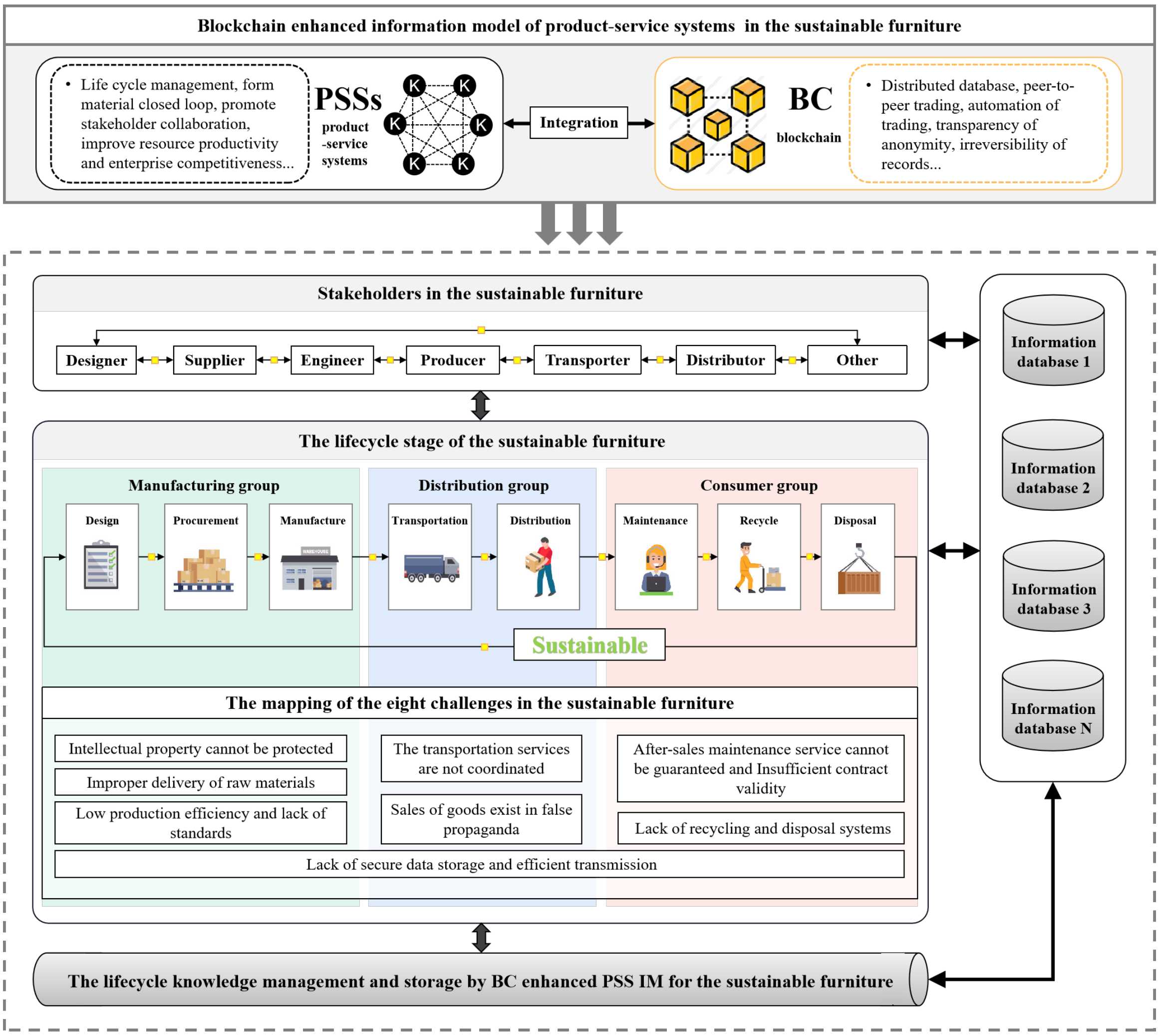

Figure 9. BC-enhanced PSSs IM in sustainable furniture (generated by authors).

5. A Conceptual BC-Enhanced PSSs IM (BC-PSSs) Framework for Sustainable Furniture

The establish of the conceptual BC-PSSs framework for sustainable furniture is based on the results of quantitative and qualitative analysis, as well as the significant lifecycle stages and associated challenges of sustainable furniture. The basic principle of the conceptual BC-PSSs framework is to use BC-enhanced PSSs as a tool to drive sustainability throughout the lifecycle of furniture and to assist stakeholders in interaction and furniture knowledge management. The conceptual BC-PSSs framework consists of a high-level framework, which is strategic, and a low-level framework, which is detailed. The numbers coded in red represent the significant process actions of BC enhance PSSs IM at various stages of the whole lifecycle of sustainable furniture to identify the potential role of BC integrated PSSs IM in the whole lifecycle of sustainable furniture and to meet the challenges of sustainable furniture.

5.1. High-Level BC-PSSs Framework for Sustainable Furniture

Based on the important stages of the sustainable furniture lifecycle, the related challenges, and the advantages of BC-enhanced PSSs IM, the conceptually high-level BC-PSSs framework consists of three layers, including the user layer, system layer, and knowledge layer, as shown in Figure 10.

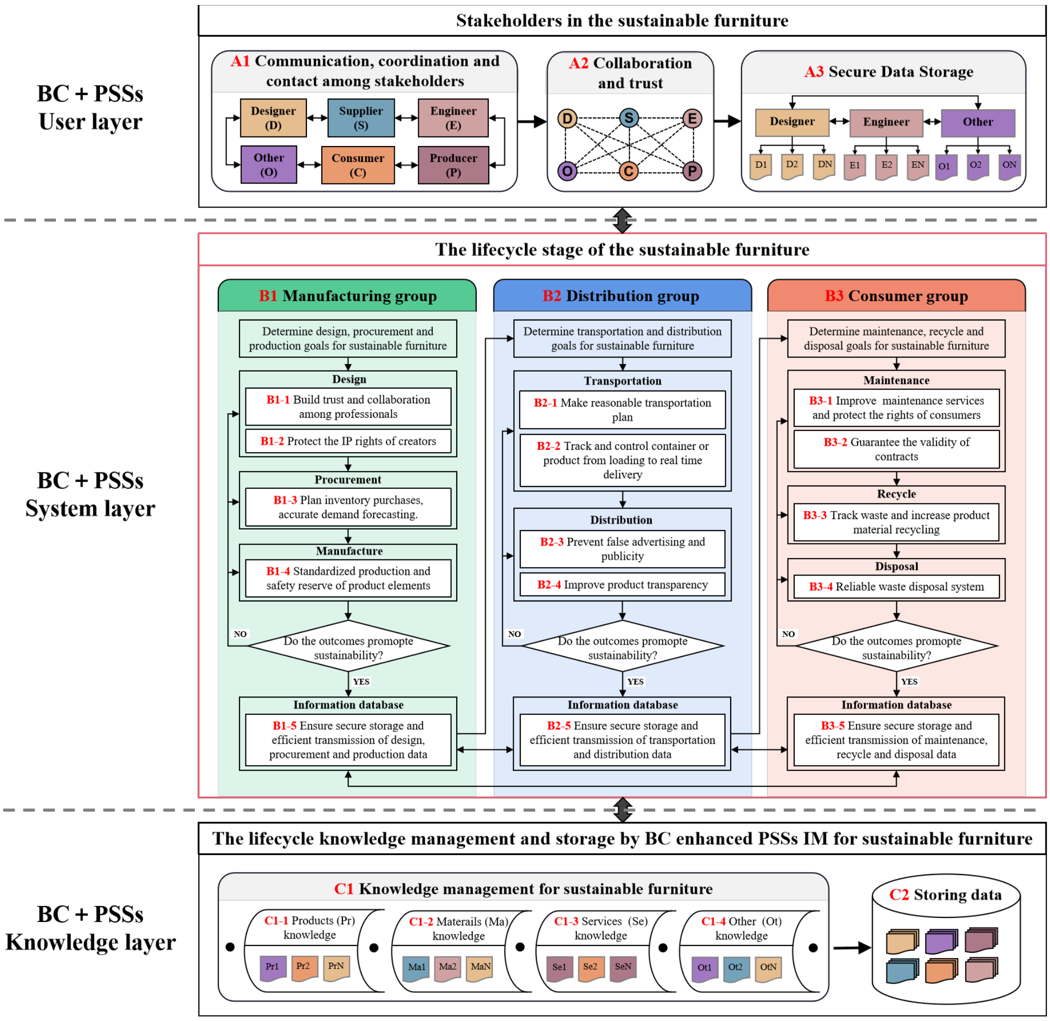

Figure 10. High-level BC-PSSs framework for sustainable furniture (generated by authors).

At the user layer, BC-PSSs underpins the exchange of information, coordination, and linkages among stakeholders in sustainable furniture (A1); guarantees effective collaboration and trust among stakeholders (A2); and securely stores relevant data (A3).

At the system layer, BC addresses the challenge of sustainable furniture PSSs IM at eight stages of the lifecycle: design, procurement, manufacture, transportation, distribution, maintenance, recycle, and disposal. It can support the collaborative operation of information collection, transmission, and communication, as well as provide a reliable basis for collaboration. In the manufacturing group (B1), BC strengthens trust among professionals (B1-1) and protects the intellectual copyright of creators (B1-2). With the advantage of BC, the procurement process enables more precise planned inventory (B1-3) and smooth production by standardizing production and secure storage of product elements (B1-4). In the distribution group (B2), the BC enables the development of a rational operational plan for the transportation process (B2-1) and the tracking and control of containers or products from loading to real-time delivery (B2-2). In the process of product distribution, the traceability and irreversibility of BC prevent false advertising and publicity of products (B2-3) and improve the transparency of products (B2-4). In the consumer group (B3), BC has the potential to protect the rights and interests of consumers in maintenance services (B3-1) and guarantee the validity of contracts (B3-2), thus extending the lifecycle of products. In addition, it improves the recovery rate of products, from tracking waste (B3-3) and establishing a reliable waste recovery system (B3-4) to the reasonable disposal of various materials and reducing environmental pollution. Throughout the lifecycle, BC ensures the secure storage and efficient transmission of all kinds of data in the design, procurement, manufacture, transportation, distribution, maintenance, recycle, and disposal stages (B1-5, B2-5, B3-5).

At the knowledge layer, BC-PSSs performs knowledge management over the entire lifecycle of sustainable furniture (C1) with the following: knowledge of production and installation of product components (C1-1), knowledge of product materials (C1-2), knowledge of product services (C1-3), and knowledge of product process methods and technical standards (C1-4). The relevant knowledge data are securely stored in the knowledge base (C2), which can provide various collection, maintenance, and retrieval functions for related resources. As a result, relevant personnel can consult their relevant expertise to alleviate the barriers posed by the lack of value information in emergency situations.

5.2. Low-Level BC-PSSs Framework for Sustainable Furniture

Figure 11 shows a conceptual low-level BC-PSSs framework on the system level. The role of BC-PSSs in sustainable furniture is specifically introduced. During the design process, collaboration between different jobs, such as design briefs, CAD, and prototypes, is established, and a database of product design information (B1-1.2) is formed by recording personal work information (B1-1.1) to strengthen trust among professionals (B1-1). Creators upload creative content to the intellectual property protection system of BC to form an intellectual property database (B1-2.3) to protect the creator's intellectual rights (B1-2). The advantages of BC include that it supports more accurate planned inventory (B1-3) by managing supplier resources (B1-3.1), negotiated contracts (B1-3.2), orders and executions (B1-3.3), and others (B1-3.4). Smooth production is achieved (B1-4) by performing material forecasting (B1-4.1), production element lists (B1-4.2), standardized production (B1-4.3), and others (B1-4.4). During transportation, BC supports the development of reasonable operating plans (B2-1) to enable containers or products from loading to real-time delivery (B2-2) by tracking the status of product components (B2-2.1), real-time information of transport drivers (B2-2.2), control transportation plans (B2-2.3), and others (B2-2.4). In the process of product distribution, BC can trace the source of the product (B2-3.1), product packaging data (B2-3.2), product QR code (B2-3.3), and others (B2-3.4), which can prevent the false advertising and publicity of the product (B2-3); improve the transparency of the product, materials, and components (B2-4) (B2-4.1); and increase consumer trust. With the support of BC, it is possible to protect consumers' rights and interests in repair services (B3-1) by defining product maintenance standards (B3-1.1), establishing maintenance institutions and services (B3-1.2), among others (B3-1.3), and extending the lifecycle of products by creating smart contracts (B3-2.2) to ensure the validity of contracts (B3-2). BC improves product recovery rates (B3-3) by effectively analyzing the degree of damage to products (B3-3.1), product recovery value (B3-3.2), product condition assessment (B3-3.3), and others (B3-3.4). In addition, it can establish a reliable waste recycling system (B3-4), classify materials (B3-4.1), and rationally dispose of various materials (B3-4.2), among other actions (B3-4.3), to reduce environmental pollution. Throughout the lifecycle, BC ensures the secure storage and efficient transmission of all kinds of data in the design, procurement, production, transportation, distribution, maintenance, recycling, and disposal phases (B1-5, B2-5, B3-5).

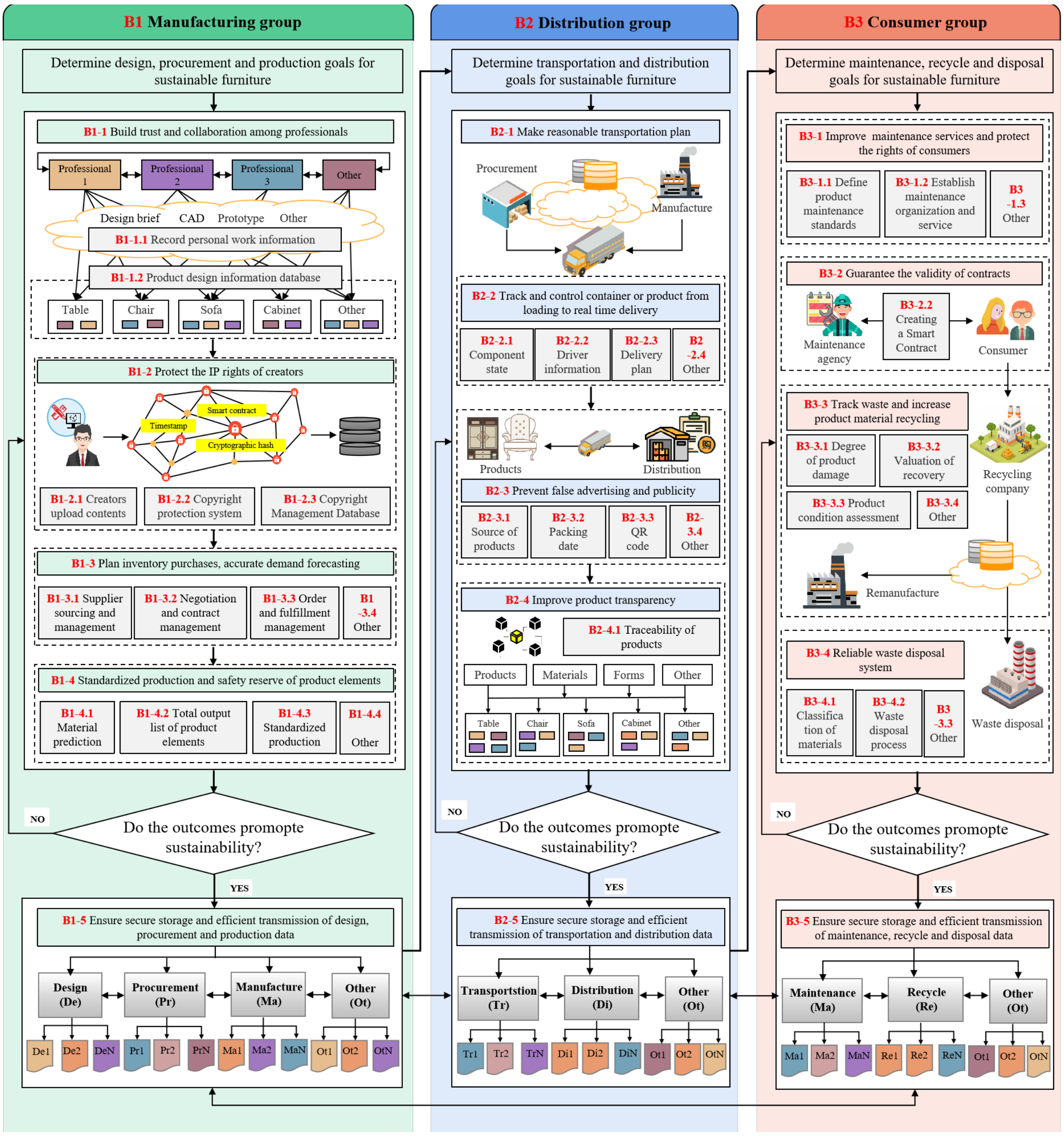

Figure 11. Low-level BC-PSSs framework for sustainable furniture (generated by authors).

6. Review and Refinement of the Conceptual BC-PSSs Framework for Sustainable Furniture

6.1. Industry-Reviewed BC-PSSs Framework

The conceptual BC-PSSs framework was accepted and presented at the 2021 CSIAM-BTAF Conference (no official publication) and reviewed by industry experts and scholars in the form of pre-interview questionnaires and interviews [78]. The content includes a three-dimensional review of the structure, content, and process of the high-level and low-level BC-PSSs conceptual frameworks, which are conducted in the form of participants first scoring the high-level and low-level conceptual BC-PSSs frameworks based on their personal views (scoring criteria of 1—strongly disagree, 2—disagree, 3—agree, and 4—strongly agree), and then presenting their own views and suggestions during the interview. The details are in Appendix A. The pre-interview questionnaire and interview were analyzed by SPSS and NVivo software, respectively. A total of seven industry experts and academics participated in this review, and Table 3 lists the demographic characteristics of the participants.

Table 3. Demographic characteristics of the participants (n = 7).

Characteristics	n	Proportion (%)
Gender		
Male	5	71.4%
Female	2	28.6%
Occupation		
Industry expert	5	71.4%
University Professor	2	28.6%
Number of years working on blockchain-related research		
Less than 5 years	1	14.3%
5–10 years	4	57.1%
10–20 years	2	28.6%
More than 20 years	0	0%

According to the results of the questionnaire before the interview, the reliability analysis of the questionnaire survey results was carried out using SPSS 22 software, and Cronbach's Alpha was greater than 0.6 and close to 1, indicating that the questionnaire had good reliability, as shown in Table 4. According to the scoring results, participants believed that the conceptual BC-PSSs framework had a clear structure, appropriate content, and clear process, as shown in Table 5.

Table 4. Reliability statistics (exported from SPSS 22).

Cronbach's Alpha	The Number of Projects
0.932	6

Table 5. Mean value of the conceptual high-level and low-level BC-PSSs framework (responses of industry experts and academics).

Evaluation Items	High-Level	Low-Level
Clarity of the structure	3.71	3.57
Appropriateness of content	3.43	3.43
Clarity of process	3.57	3.43

Based on the results of the interview, the original text of the interview was analyzed qualitatively using NVivo 11 software. Table 6 shows the core nodes, number of nodes, representative nodes, and representative interview texts. The interview transcript is coded into a total of five nodes, including "stakeholders", "strategies", "technologies", "institutions", and "policies". Participants in stakeholder-related issues mainly talked about correlation of "data", "data update", "collaborative communication", and "information sharing"; in the policy-related issues, the participants mainly mentioned "decentralized management", "mathematical model", "reward system", and "lifecycle management"; in the institution-related issues, the participants mainly involved "value assessment system", "a unified platform", and "the central institution"; in technology-related issues, the participants mainly mentioned "copyright protection", "roots", and "wisdom contracts"; participants in policy-related issues mainly involved "corporate policy" and "the government's policy". Figure 12 shows the node distribution.

Table 6. The encoding results of the interview transcripts via NVivo 11 software.

Core Nodes	Number of Nodes	Representative Nodes	Representative Interview Texts
Stakeholders	10	Correlation of data Data update Collaborative communication Information sharing	Blockchain can enhance data correlation between designers and consumers.
Strategies	8	Decentralized management Mathematical model Reward system Lifecycle management	Blockchain solves the problem by building relationships between different businesses in a decentralized setting.
Institutions	7	Value assessment system A unified platform The central institution	Blockchain enables data to be recorded on a chain so that its value can be assessed. This requires the enterprise to establish the value evaluation system, through some standards and rules to evaluate the value.
Technologies	7	Copyright protection Roots Wisdom contracts	Copyright protection is now a relatively mature technology in blockchain.
Policies	4	Corporate policy The government's policy	Whether blockchain can be successfully implemented in this industry depends on the willingness of enterprises to do it, and needs the support of enterprises.

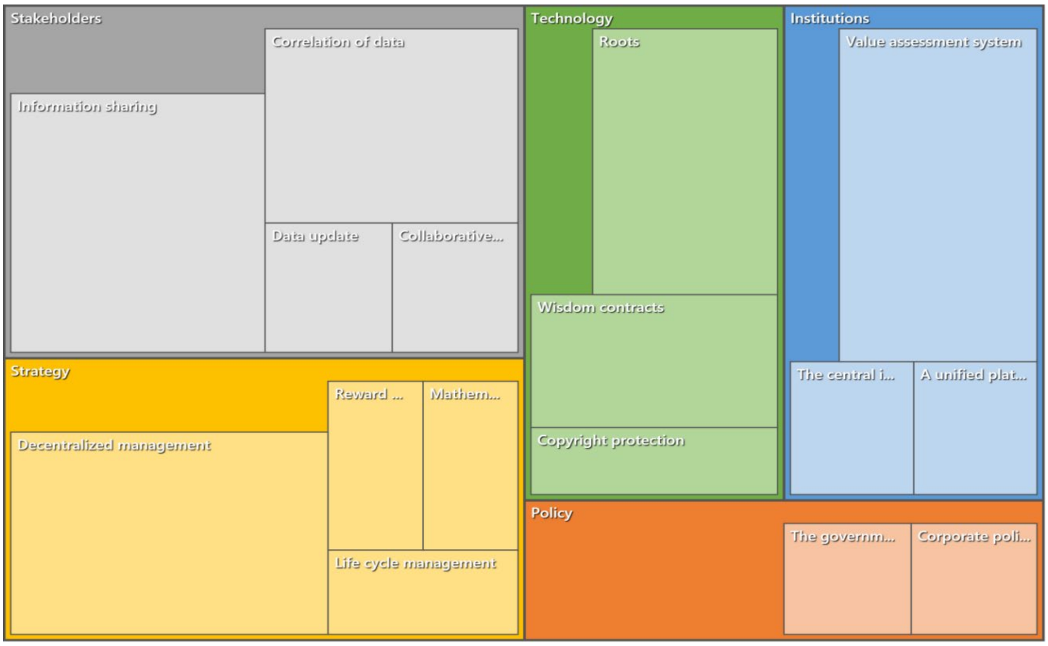

Figure 12. Node distribution (exported from NVivo 11 software).

Subsequently, NVivo11 software was used to analyze the interview word frequency. As shown in Figure 13, the participants repeatedly mentioned the following words "value", "blockchain", "data", "design", "contracts", "need", "product", "consumer", and "contribution". Data transmission and storage for the sustainable furniture lifecycle and collaboration between stakeholders have attracted the attention of respondents. Introducing BC into a sustainable furniture lifecycle can improve trust among stakeholders, enhance data connectivity, and reduce information errors. In order to encourage the value contribution of stakeholders, a value evaluation system can be established to record value through pricing, appraisal, and performance. However, BC is implemented in the lifecycle stage of sustainable furniture, which requires central agency management and needs to standardize furniture product components to reduce the cost of BC establishment.

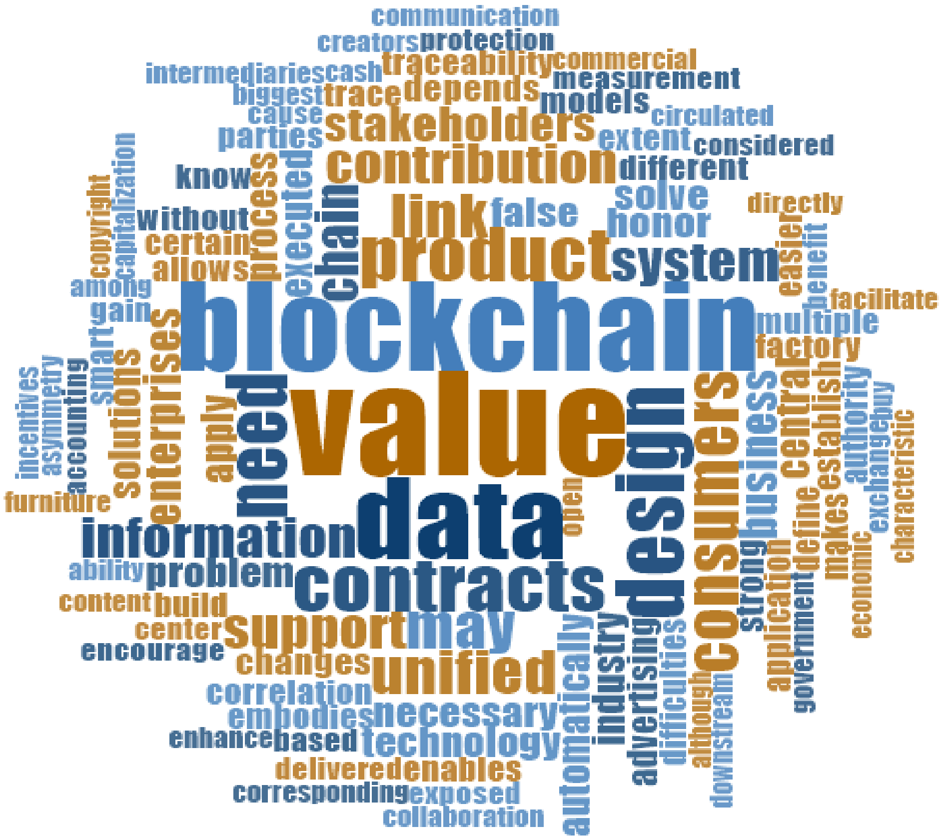

Figure 13. Interview word frequency (exported from NVivo 11 software).

During the interviews, participants noted that BC has great potential in enhancing PSSs IM and addressing challenges in the sustainable furniture lifecycle. In addition, participants made a number of useful suggestions to strengthen the content of the conceptual BC-PSSs framework, including the following:

1. BC can facilitate the design of incentives to encourage stakeholders to contribute personal knowledge.
2. BC can strengthen the data relevance between designers and consumers. There is an information asymmetry between the designer and the consumer through the enterprise or factory.
3. For the challenges of the furniture lifecycle, BC may not be able to prevent false advertising and publicity, just as we cannot prevent car accidents. Of course, BC can reduce false advertising and publicity to a certain extent because it can be traced, queried, and verified. This lets consumers understand the source of products, product materials, and production information.
4. BC enables data to be recorded on the chain for value assessment. This requires enterprises to establish a value evaluation system and evaluate value through some standards and rules.

6.2. The Updated BC-PSSs Framework

Refinements were made at the user layer and system layer of the high-level conceptual BC-PSSs IM framework as suggested by industry experts and scholars. As shown in Figure 14, at the user layer, "reward" was added in A1 and upgraded to "reward mechanism facilitates stakeholders communication and information sharing", In addition, we added A4 "stakeholders value recording and evaluation". At the system layer, we modified B2-3 "prevent false advertising and publicity" to "reduce false advertising and publicity".

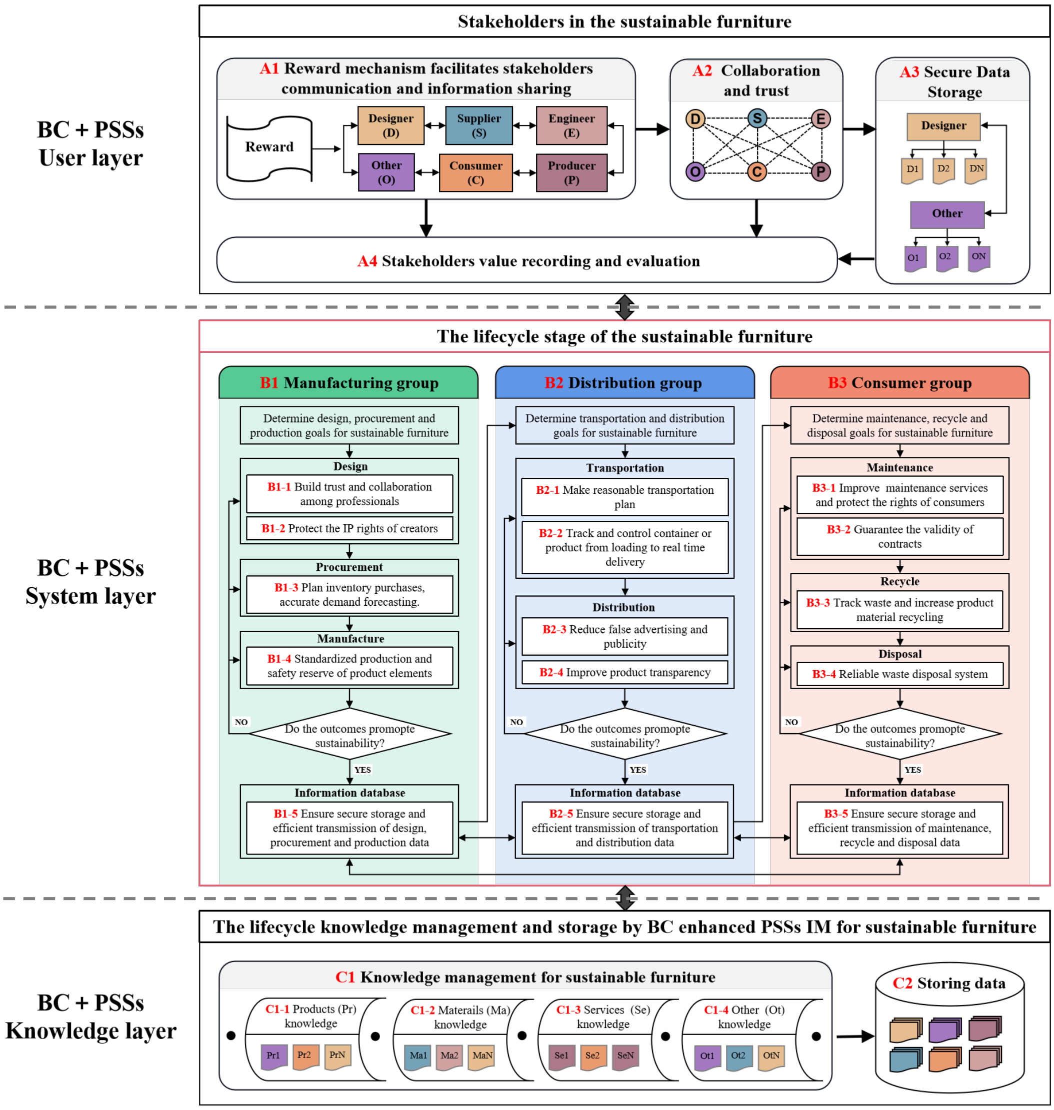

Figure 14. The updated high-level BC-PSSs framework (generated by authors).

7. Discussion

7.1. Conceptual BC-PSSs Framework Contributes to Sustainable Furniture

In this paper, the conceptual framework of BC-PSSs is established to apply BC and PSSs IM to the whole lifecycle of furniture to promote its sustainable development. The framework presents eight stages of furniture design, procurement, manufacture, transportation, distribution, maintenance, recycle, and disposal, and it fully responds to the challenges from the user layer, system layer, and knowledge layer, respectively. In the user layer, BC and PSSs IM are used to address stakeholder-related issues such as collaboration, information sharing, valuation, and data storage. In the system layer, BC and PSSs IM are used to address issues at various stages of the lifecycle, such as proper transportation planning. In the knowledge layer, BC and PSSs IM are used to deal with issues related to knowledge management, such as product knowledge and material knowledge.

The BC-PSSs framework shows that PSSs IM provides effective product–service lifecycle activities for furniture lifecycle management, linking reliable products and value-added services as a system. Through the furniture product lifecycle knowledge management, we can reasonably and effectively provide required knowledge for stakeholders. At the same time, providing customers with maintenance and recycling services is conducive to forming a closed loop of materials and reducing the resource consumption of furniture products. In addition, it can contribute to promoting stakeholder collaboration and improving corporate competitiveness and resource productivity. BC can monitor products throughout the lifecycle of furniture and gather important information and data to better design, produce, sell, use, and recycle. BC also provides a way to enhance the feasibility of sharing data across the product lifecycle, facilitate stakeholder engagement, and bring trust to all parties. In addition, BC makes the furniture lifecycle transparent and traceable, which can further close the product lifecycle and reduce gas emissions and waste generation. BC can not only bring advantages to the furniture lifecycle, but also improve the traditional PSSs lifecycle management from multiple aspects, providing support for improving data storage transmission, security, trust, privacy, and other issues in the furniture PSSs lifecycle. BC can reasonably manage the products, services, information, and data generated throughout the lifecycle of PSSs IM, and securely track and trace products, helping PSSs IM effectively trigger services and delivery services and overcome the problem of data insecurity and low trust between stakeholders.

This study shows that BC has the potential to promote the implementation of PSSs IM in sustainable furniture and jointly address the challenges of sustainable furniture lifecycle, which is mainly reflected in the protection of creators' intellectual property rights, effective inventory management of raw material procurement, improvement of standardized specifications and production of product elements, effective execution of logistics planning and transportation management, improvement of consumer trust in the distribution process, improvement of maintenance services and contract effectiveness, improvement of waste recycling and treatment systems, and ensuring safe storage and efficient transmission of data.

7.2. The Potential of BC-PSSs to Quantify Design Value in Sustainable Furniture

According to Section 4.2.1 of this paper, the design casts a deep "environmental shadow" on the downstream processes of the lifecycle and has an impact on the entire lifecycle. Therefore, the decisions made during the design phase are crucial and come mainly from the designer. According to Section 4.2.5, the BC technology timestamp, asymmetric encryption, tamper-proof features, and transparency can bring advantages to protect the rights and interests of designers. Therefore, this section specifically discusses how BC-enhanced PSSs IM encourages designers to create more design value and discusses its potential in value quantification.

Currently, design is increasingly present in the context of companies, and the value created by its implementation, as well as the possibilities of management, become crucial. Design can innovate the image of a business, optimize costs, and develop innovative products and services; help maintain product quality in terms of function, production, economic, and social culture; and improve the competitiveness of enterprises [82]. The stakeholders (designers) involved in the design activities play an important role at this stage, and the creative freedom of designers can affect the materials and characteristics of the final product [1]. Designers can choose and determine the material, formal and practical, and some other aspects of furniture during the design process, influencing the emotional response of consumption and thus consumer behavior [125]. For example, designers can raise consumers' awareness of the environment by designing websites, advertisements, brochures, and other promotional materials, and they can communicate with consumers about the benefits of using such products [109]. Therefore, the value of design activities is not only reflected in commercial value and material benefits, but also in ecological values and social responsibility.

The value created by designers needs to be recognized and acknowledged because there is a positive cycle between value creation and member benefits; that is, value creation requires the participation and contribution of members, and members need to be able to enjoy the benefits of value creation. However, furniture designers currently lack the encouragement to express their ideas and designs. Each stakeholder in an organization has a certain amount of personal knowledge, and due to the lack of reasonable, feasible, and mandatory sharing reward mechanisms, contributors are not motivated to share knowledge and are reluctant to contribute their knowledge to other organizations [115,126,127]. This will affect designers to create more valuable products to some extent.

The "blockchain revolution" has brought a paradigm shift to the creative economy [128]. First of all, BC technology can store and manage information, such as intellectual property rights, and reflect the design value of creators through secure sales and transactions. BC makes the lifecycle management of intellectual property works more convenient and transparent, including creation, registration, and transaction [103]. Through trading, creators can obtain the economic benefits of their works more directly and realize the value of intellectual property works. At the same time, this can stimulate the enthusiasm and motivation of creators [129], thereby inspiring people to make meaningful contributions to a common goal. Second, BC is a means of recording specific states of affairs agreed upon by the network in a secure and verifiable manner [130]. Data on the BC are time-stamped and immutable, which is ideal for tracking members' activities and ensuring accountability for all data published [131]. For example, after the product design is completed, the BC can record the raw materials and energy consumed by the product, the exhaust gas and waste emitted, the environmental impact caused by use, the degree of product material recycling, the energy consumption and pollution generated by waste disposal, etc., so as to evaluate the social and ecological value created by the designer. In addition, one of the most promising features of BC technology as a medium for value recording is decentralized value recording, capable of encapsulating qualitatively different contributions [132]. Now, more and more consensus mechanisms are being proposed, such as Proof of Value (PoV); PoV protocols provide a mechanism for decentralized consensus that determines the value of each contribution, which can equally reward smart contracts that generate value [133]. BC is used to record all design attempts in architectural design, recording the value contribution of creators in solving design problems [134].

Recently, the concept of non-fungible tokens (NFTs) has emerged in the BC world as a unique way to attribute ownership to digital assets [135]. NFTs are tradable rights to digital assets (pictures, music, movies, and virtual creations) where ownership is recorded in a BC smart contract. NFTs have been used as a way to reward content creators, provide intellectual property protection for creators, make it easier to buy and sell patents, and enable creators to benefit from innovation [136]. Due to the rapid development of various new technologies, the digital economy will enter the 3.0 era, and BC and the metaverse are the infrastructure that will support the digital economy 3.0. Digital assets will become a very important way to display value in the metaverse [137]. Paired with the metaverse, NFTs represent a major advancement and revolution in the field of virtual reality and BC, providing content creators with new ways to express their unique and valuable work [138].

7.3. The Potential of BC-PSSs to Improve Consumer Behavior in Sustainable Furniture

According to Sections 2.1 and 4.2.1 of this article, the sustainability of furniture is largely influenced by consumer behavior, especially in terms of product longevity. Therefore, improving consumer behavior is particularly important for environmental protection and sustainable development. At the same time, according to Section 4.2.5, BC technology can bring advantages to consumers through traceability, irreversibility, and smart contracts. Therefore, this section will discuss specifically how BC-enhanced PSSs IM brings potential to promote sustainable consumer behavior.

Consumer behavior is an act or activity of a consumer to select, use, and dispose of a product or service. This includes not only purchases, but also ideas, suggestions, and actions related to consumer purchasing behavior. The essence of consumer behavior is the activity of consumers to meet their needs by purchasing products or services [139]. In the consumer behavior literature, environmentally sustainable behavior is often described as green consumption activities [140,141]. Consumer green behavior is an important sub-area of sustainable development, including recycling, waste reduction, local consumption, energy saving, reuse, maintenance, and other ecological behaviors, which are often summarized into three main categories of behavior, purchasing behavior, use behavior, and end-of-use behavior [142].

The general transformation of consumer behavior is the core of sustainable consumption [143]. Researchers have proposed a variety of ways to change consumer behavior, for example, through the use of mandatory regulatory and legal mechanisms to promote waste treatment services [144]; providing adequate information through educational services has been shown to be effective in changing consumer behavior, including educating consumers about the proper installation, use, maintenance, and disposal of products [145]. With the enhancement of consumers' awareness of environmental protection, the furniture industry has introduced the concept of green furniture and conveyed the characteristics of environmental protection and social expectations of products to the final consumers through the form of eco-labels [146]. However, due to various counterfeiting problems, consumers have doubts and distrust of eco-labeled products [147,148]. Therefore, it hinders the promotion of eco-friendly furniture. BC technology can improve information traceability and increase consumer confidence in their products, providing consumers with true and transparent information. In addition, BC records help monitor and prove the environmental sustainability of the products produced to customers [13]. IKEA has applied BC technology to green and sustainable supply chain management as a guarantee that the entire process is controlled and that the final product is indeed made of said specific wood [149]. BC can facilitate the design of incentives to encourage green behavior among consumers, improve visibility, increase efficiency, and support performance monitoring and reporting. At the same time, native tokens on digital platforms can promote green behavior for consumers and other participants during the product lifecycle [142]. Mechanisms, such as BC certification of suppliers, inspectors, and IoT sensors, can be used to verify the ecological behavior of individuals [150], and consumers' sustainable behavior can be rewarded through tokenization. Some organizations are already using BC to encourage sustainable behavior among consumers, such as CarbonX rewarding consumers who purchase carbon-neutral products based on assessing the carbon footprint of products and services, and Recycle To Coin rewarding consumers who return recyclables to collection sites [142].

In summary, we can enhance product lifecycle visibility by incentivizing individual participation in promoting green behaviors, facilitating the tracking of a product's actual footprint, and improving the efficiency of emissions trading schemes by reducing fraud and improving system fidelity [149]. BC plays a particularly important role in sustainability, with its potential to alleviate some of the sustainability-related challenges and facilitate the realization of a CE [151].

8. Conclusions

With the increasingly serious problems of resource shortage and environmental damage, especially under the impact of COVID-19, sustainable development has become even more urgent. As an indispensable item in people's daily life, furniture has the characteristics of consuming a large amount of raw materials and generating waste, and it still needs to continue to explore and make progress in the development of sustainability. The PSSs can effectively manage the lifecycle and has the potential to develop sustainable furniture and promote CE, so this paper applies the PSSs to the lifecycle of furniture, carries out lifecycle knowledge management, promotes stakeholder collaboration, forms a material closed loop in the lifecycle, improves resource productivity, and enhances enterprise competitiveness. Although the PSSs brings a series of benefits to the sustainable development of the furniture industry, it is still necessary to consider how to ensure the secure storage and transmission of information and data in the PSSs lifecycle, as well as the rights and interests of stakeholders and other problems. BC has the characteristics of distributed database, peer-to-peer transactions, transaction automation, anonymity, and irreversibility of records in terms of ensuring data security, opening up a treasure trove of renewable digital possibilities for the goal of sustainable CE. This paper uses the potential advantages of BC to solve the challenges of sustainable furniture PSSs from the perspective of lifecycle and further promote the sustainable development of the furniture industry.

This paper attempts for the first time to construct an overview BC-enhanced PSSs framework for sustainable furniture from the whole lifecycle stage; it constructs a high-level framework including three levels of user, system, and knowledge from a strategic perspective, and it constructs a low-level framework of the system layer according to specific details. The framework adopts a mixed quantitative and qualitative method, and first quantitatively analyzes the potential relationship between furniture, PSSs, and BC through VOSviewer. Then, it qualitatively analyzes the lifecycle stages of sustainable furniture, the advantages of PSSs in promoting sustainable furniture, and the potential of BC to enhance PSSs IM to further promote sustainable furniture and solve related challenges. Subsequently, the conceptual framework of BC-PSSs is constructed, reviewed, and refined through pre-interview questionnaires and follow-up interviews with industry experts and scholars. In addition, this article explores the potential of BC-PSSs to quantify the value of designers at the design stage through intellectual property, reward mechanisms, and NFTs to promote the value contribution of designers. BC-PSSs has the potential to improve consumer purchase, use, and post-use behavior to promote sustainable consumer behavior in furniture consumption. The study shows the potential promise of using a PSSs in promoting sustainability and CE in the furniture industry, as well as the potential of BC to enhance PSSs IM to solve furniture lifecycle challenges. The results can provide reference for researchers and policy makers in related industries. More importantly, the study contributes to the achievement of SDGs 11 (Sustainable Cities and Communities) and SDGs 12 (Responsible Consumption and Production). However, the quantitative analysis based on VOSviewer software in this paper mainly focuses on the WOS core collection database, and subsequent studies can quantitatively analyze multiple databases, such as Scopus and Science Direct. At the same time, the conceptual BC-PSSs framework has been reviewed by industry experts and scholars, and more work needs to be done in the future to ensure its practical feasibility and practical significance.

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Appendix A

The purpose of this survey is to review and refine the conceptual BC-PSSs framework for sustainable furniture. The content includes a three-dimensional review of the structure, content, and process of the high-level and low-level BC-PSSs conceptual frameworks, which are conducted in the form of participants first scoring the high-level and low-level conceptual BC-PSSs frameworks based on your personal views (scoring criteria of 1—strongly disagree, 2—disagree, 3—agree, and 4—strongly agree), and then presenting your own views and suggestions.

1. High-level BC-PSSs framework for sustainable furniture

(1) The structure of the high-level framework is clear. 1 2 3 4
(2) The content of the high-level framework is appropriate. 1 2 3 4
(3) The process of the high-level framework is clear. 1 2 3 4

2. Low-level BC-PSSs framework for sustainable furniture

(1) The structure of the low-level framework is clear. 1 2 3 4
(2) The content of the low-level framework is appropriate. 1 2 3 4
(3) The process of the low-level framework is clear. 1 2 3 4

3. The BC potential to overcome challenges for PSSs IM in sustainable furniture

(1) Protection of the intellectual property rights of creators. 1 2 3 4
(2) Effective inventory management of raw material procurement. 1 2 3 4
(3) Improving the standardization and production of product elements. 1 2 3 4
(4) Effectively implement logistics planning and transportation management. 1 2 3 4
(5) Improving consumer trust in the distribution process. 1 2 3 4
(6) Improving maintenance services and contract effectiveness. 1 2 3 4
(7) Improving the waste recycling and treatment system. 1 2 3 4
(8) Ensuring secure storage and efficient transmission of data. 1 2 3 4

4. Further Comments Please add any additional comments about the conceptual BC-PSSs framework in the space below. Thank you very much for participating in this study!

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