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Designing a Digital Service System for Sustainable Social Value Creation: A Holistic Design Method Based on Socio-Cyber-Physical System Perspectives

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Abstract: Recently, data utilisation and digital service offerings are becoming primary methods of value creation. In this context, designing and offering 'digital service systems' (DSSs) that integrate physical elements (e.g., products, facilities, and physical infrastructure) and digital service elements (e.g., digital services, data, apps, and cloud systems) are important to create sustainable social values and achieve the United Nations' Sustainable Development Goals 9 and 11. In this study, we propose a novel method for designing a DSS that simultaneously consider three system domains, namely social, physical, and digital domains. Specifically, we developed design models and a design process to support the DSS design. The proposed method was applied to an actual DSS design case. The results revealed that the proposed method could effectively consider components in the social system domain in addition to those in the digital and physical system domains in the DSS design. In particular, we identified that the proposed design models were useful for enabling the systematic management of a long-term collaborative design process among various stakeholders. They also enabled value-oriented thinking in DSS design and encouraged designers to consider different types of value in the DSS.

Keywords: digital service system; design model; design process; socio-cyber-physical system; social innovation

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1. Introduction

Digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), and big data processing have rapidly evolved in recent years. In this digitalised society, various products and services are interconnected through digital data [1]. Therefore, in various industries, data utilisation and digital service provision have emerged as key methods for value creation [2]. In this context, initiatives to develop and apply digital technologies and services to solve urban problems (e.g., healthcare, ageing populations, and environmental issues) are actively discussed and promoted in various countries under the umbrella concepts of 'digital city [3,4]' or 'smart city [5,6]'. These initiatives aim to create sustainable social values through the implementation of digital technologies and services and thus correspond to Goal 9 ('Industry, Innovation and Infrastructure') and Goal 11 ('Sustainable Cities and Communities') of the United Nations' 17 Sustainable Development Goals (SDGs) [7]. In addition, the servitisation and digitalisation of the business model in the manufacturing industry have attracted considerable interest [8].

Designing and developing systems (or solutions) that integrate physical elements (e.g., products, facilities, and physical infrastructure) and digital service elements (e.g., digital services, data, apps, and cloud systems) to create user value and address urban (social) problems are becoming increasingly important [9]. The concept of a digital service system (DSS) has been proposed to encompass and discuss systems that integrate physical products and digital services [10,11]. In DSS and related fields, various methods are employed to design systems that seamlessly integrate physical products and digital services, thereby effectively creating user and social benefits [12].

Simultaneously, many studies have emphasised the importance of considering interconnected social systems (e.g., organisational rules, social institutions, culture, and customs) in addition to physical products and digital services to achieve the social utilisation and diffusion of digital technologies [13]. For instance, in the context of designing smart mobility service systems that utilise innovative automated driving technologies, the social implementation of the system will not be realised unless laws and regulations regarding accidents caused by automated vehicles are established. Therefore, the design space of DSSs must encompass not only the physical system and digital service domains but also the social system domain [11]. As layers of these three systems are significantly different [13], designers find it challenging to design the overall structure of a DSS while relating each system's components to each other. Although previous studies in design theory and methodology research have argued the necessity of integrating digital, physical, and social systems, they only present abstract and conceptual design methodologies [14]; design methods that comprehensively consider these three perspectives (i.e., social systems, physical systems, and digital services) have not been established.

Therefore, in this study, we aimed to develop a DSS design method that simultaneously considers the three domains of social, physical, and digital systems. In addition, we applied the proposed method to the design of smart personal mobility services in a Japanese smart city to clarify its usefulness and identify challenges with its implementation.

The remainder of this paper is structured as follows: Section 2 describes related studies that serve as the theoretical background for this study and highlights current research gaps. Section 3 delineates the research approach employed in this study. Section 4 proposes a design method that enables designers to consider social, physical, and digital systems comprehensively. The concept of the proposed design method is initially described, and the concrete design process is subsequently presented. Section 5 illustrates a case study where we implemented the proposed methods in a DSS design project (i.e., a smart mobility service design project) in a Japanese smart city. Section 6 discusses the utility and limitations of this study, while Section 7 presents the conclusions and future prospects.

2. Theoretical Background and Literature Review

2.1. Digital Service Systems

In this section, several system concepts related to DSSs, such as smart service systems, smart product–service systems (PSSs), and socio-cyber-physical systems, are reviewed.

2.1.1. Service and Service Systems

Scholars in service studies have discussed the definition of 'service'. In service science research, the term 'service' has been defined as 'the application of competence for the benefit of another' [15]. This definition considers service as the application of resources (e.g., people, organisations, information, technologies, and products) to benefit another party. Thus, a service can be regarded as a configuration of tangible (e.g., people and products) and intangible (e.g., information, knowledge, and activities) elements that mutually co-create value. In this field, the term 'service system' refers to the collective structure of interactions among the various entities that construct a service [16]. More precisely, a service system is defined as 'a dynamic value-co-creation configuration of resources, including people, organisations, shared information (e.g., language, laws, measures, and methods), and technology' [17].

2.1.2. Service Systems and Digital Technologies

This section introduces several concepts related to service systems that utilise digital technologies, as proposed in the field of service studies.

In the service science field, the 'smart service system' concept has been proposed [18,19] and defined as 'a service system capable of learning, dynamic adaptation, and decision-making that requires an intelligent object and involves intensive data and information interactions among people and organisations' [12]. Therefore, the smart service system concept focuses on the intelligence of service systems, which is primarily enabled by AI- and IoT-based technologies.

In the manufacturing and engineering fields, the 'smart PSS' concept refers to an integrated solution that combines products and digital services [20]. Specifically, a smart PSS is referred to as 'an information technology (IT)-driven value co-creation business strategy that integrates products and e-services' [21]. Research on smart PSSs originated in the context of digitisation and servitisation in the manufacturing industry [22]. Therefore, the smart PSS concept focuses on the integration of physical products and digital services, particularly in the manufacturing industry. For instance, in smart PSS studies, smart manufacturing products (e.g., a heating system with remote monitoring services) [23], smart appliances (e.g., smart water dispensers) [24], and connected bikes [25] have been used as case studies. As a comparable system concept to smart PSSs, Halstenberg et al. [26] have proposed the concept of 'smart services', which is defined as 'platform-centred value creation systems that contain intelligent products or data-driven services and place the individual customer benefit at the centre of value creation'. They explained that 'smart services can be described as a specific manifestation of PSSs'; this concept is encompassed in smart PSSs. Furthermore, Zheng et al. [20] introduced other system concepts similar to smart PSSs, such as cyber-physical PSSs [27] and digitalised PSSs [28].

In the service engineering and design fields, the DSS concept has been proposed [10]. A DSS refers to a service system integrating various tangible (e.g., humans, organisations, and products) and intangible (e.g., activity, information, digital technologies, and data) components designed and developed to solve social problems and achieve social innovation [11]. In contrast to smart PSSs, manufacturing products do not necessarily play a central role in value creation in the DSS concept. In this sense, a DSS is based on the concept of a service system, which denotes the configuration of tangible and intangible elements. However, the DSS concept is distinct from the smart service system concept in that it does not exclusively focus on using AI technologies to enhance the intelligence of service systems but rather on using digital technologies in a broader context (e.g., increasing productivity through digitisation). In other words, the DSS concept more generally and directly emphasises the context of a service system that incorporates digital technologies, regardless of whether it possesses AI-like intelligence or focuses on manufacturing products [11].

Therefore, in this study, we used the DSS concept, which covered a broader scope of digital technologies, as it focused on the design of service systems that integrated various digital technologies (beyond simply AI) to create social value or achieve social innovation.

2.1.3. Socio-Cyber-Physical Systems

No technological system can be decoupled from the social system, which serves as the environment in which the technology is employed. For instance, information systems in the workplace are used and operated in accordance with business processes, organisational structures, and internal rules. In social science studies, the socio-technical systems (STSs) concept has traditionally been used to integrate technological and social systems [29]. In STSs, all technological systems are embedded in a relationship with the social system, which consists of people, organisations, and rules [29].

A DSS, the focus of this study, is a system that involves various interactions between the digital and physical worlds [10]. In a DSS, data obtained from various people and objects in the physical world are analysed and processed via cloud systems and algorithms in the digital world. The analysis results are subsequently utilised in the physical world to generate beneficial value for users and stakeholders. This type of system, which focuses on complex interdependencies and interactions between the cyber (i.e., digital) space and the physical world, is commonly referred to as a cyber-physical system (CPS) [30]. Therefore, the DSS can be regarded as a CPS.

Recently, the widespread adaptation of digital technologies has resulted in concerns regarding their negative impact on society, such as breaches of privacy and data bias in AI [31]. Inspired by the STS concept, a growing number of studies have emphasised the importance of introducing a social system perspective when designing and developing CPSs. Rijswijk et al. [14] proposed the 'socio-cyber-physical system (socio-CPS)' concept to refer to a system integrating an STS and CPS. It is defined as 'a system composed of the social (people), digital (data), and physical (things) worlds'. Within the socio-CPS concept, societal values are created through mutual interactions among these three domains (Figure 1). In addition, Wang et al. [32] discussed the concept of a cyber-physical social system (CPSS) as a system that effectively combines the cyber, physical, and social spaces. In particular, to realise social problem-solving and social innovation using CPSs, the social system domain needs to be incorporated into the design space, as intended by the socio-CPS and CPSS concepts. Therefore, in the context of DSS design, designers should comprehensively consider not only the elements of the physical and digital worlds but also the social system, which serves as the environment in which the designed system is used and operated.

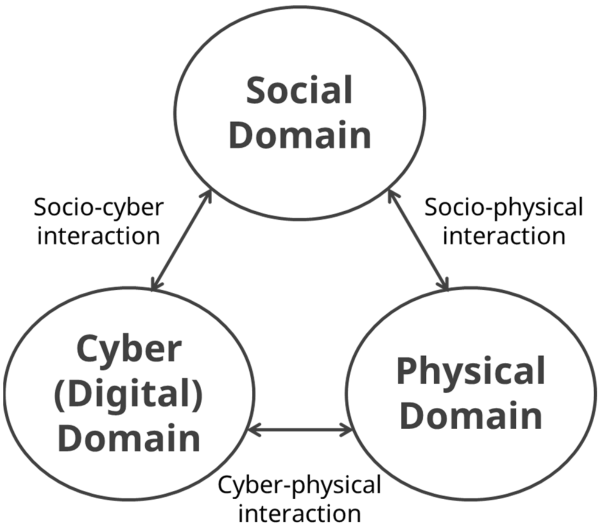

Figure 1. Socio-cyber-physical system [14].

2.2. *Literature Review on the Socially Conscious DSS Design*

In this section, we review the recent studies related to DSS design and modelling.

2.2.1. Design of Digital Service Systems

Recently, studies have been conducted to develop methods and frameworks to facilitate the design of service systems that integrate digital technologies [13]. Previous studies have been conducted using various related concepts, such as smart service systems, smart PSSs, smart services, and DSSs. Although this study focused on the DSS concept, we conducted a literature review that encompassed these related fields.

Previous studies have primarily focused on assisting in the conceptual design phase. For example, Boucher et al. [23] developed a modelling language to describe the conceptual prototypes of a smart PSS. In addition, they developed a toolkit (i.e., a software tool) to describe and manage conceptual models of smart PSSs. Halstenberg et al. [26] developed a model-based design methodology for smart services that could contribute to the circular economy. In addition, they developed a modelling language to accurately depict the detailed functional structure of smart services. Tsunetomo et al. [33] proposed a conceptual design process for smart PSSs that considered the social and ethical impacts of digitalisation. These existing studies offer conceptual models for designing smart PSSs and smart service system structures.

Recent studies have offered more practical tools. For instance, Akasaka et al. [11] developed a framework to analyse the holistic context and derive a future vision of DSSs from three perspectives, namely social (e.g., policy and citizen needs), digital (e.g., digital systems and data), and physical (e.g., products and urban infrastructure) perspectives. Li and Lu [34] developed a blueprinting framework called the smart service blueprint scape. This framework is used to describe and design AI-enabled smart services with a specific focus on the user experience dimension. Poeppelbus and Durst [35] introduced a canvas tool known as the Smart Service Canvas, which is used to design the basic framework of a smart PSS. The canvas comprises three major categories, which are value, customer needs/pain, and a digital platform. These studies provide practical tools for designers and stakeholders to conduct collaborative discussions and workshops during the conceptual design phase.

Furthermore, previous studies proposed several mathematical methods to facilitate more quantitative and objective decision-making and design concept selection in the conceptual design phase. For example, Yang et al. [36] proposed a method for quantitatively and objectively evaluating the emotional value of designed concepts in smart PSSs. Liu et al. [37] developed a method for quantitatively evaluating co-creative value propositions in smart PSSs, encompassing multiple dimensions, such as sustainability, usability, safety, and reliability. These studies aim to optimise the execution of the complex design process of smart PSSs by introducing quantitative and objective methods.

2.2.2. Socio-CPS Modelling

As the socio-CPS (or CPSS) is a new system concept that has recently emerged, many previous studies have attempted to clarify the definition of its concept and research trends through systematic literature reviews. For example, Sobb et al. [38] conducted a systematic review of the CPSS in the cyber security field and clarified the CPSS concept and its major research trends. Based on a systematic review of the CPSS concept, Yilma et al. [39] proposed a generic (i.e., not field-dependent) definition and a rigorous formulation based on systems theory.

Furthermore, scholars have recently discussed how to model the structure of socio-CPS or CPSS. Generally, modelling and visualising the system structure support the thinking process and discussions of designers. Therefore, studies on socio-CPS/CPSS modelling are closely related to the scope of this study, as it supports the DSS design process by visualising the structure of systems that integrate digital, physical, and social systems. In a study on socio-CPS modelling, Liu et al. [40] modelled a socio-CPS that presents a delivery drone system, including social factors such as safety- and sustainability-related regulations. Mannari et al. [41] proposed a general modelling method for a socio-CPS based on their case of digital agriculture system development. Particularly, their study proposed a method that integrates existing system modelling methods such as UML, iStar, and BPMN [41]. Their proposed method was validated through case studies [42]. Anda et al. proposed a method for managing the traceability between multiple sub-models of socio-CPS [43]. Maamar et al. [44] defined the three components of a CPSS (i.e., data artefacts, thing artefacts, and social artefacts) and developed design guidelines based on their relationships. These studies on socio-CPS modelling have mainly focused on the modelling schemes for visualising the complex structure of socio-CPSs.

2.2.3. Socially Conscious Design Approach

When considering the wider scope of design studies, several design methodologies that explicitly incorporate the social system perspective into the design process have been proposed in recent years. For example, Irwin [45] proposed the ‘Transition Design’ approach, in which the design process commences with a vision of the future social system to be realised rather than technological seeds, such as digital technologies and systems. Joore and Brezet [15] developed a multilevel design methodology (MDM) that presented a conceptual framework and process for concurrently designing social systems (e.g., policies, laws, and rules), technological systems, and PSSs.

These design approaches that explicitly include the social system perspective in their design process emphasise the importance of the inclusion of the social system perspective in the design space, but they present only abstract and conceptual design methodologies. These approaches have not established concrete design procedures and supporting frameworks.

2.3. Research Gap

To achieve the social implementation of digital technologies and realise social innovation, it is crucial for DSS designers to comprehensively consider not only the digital and physical system but also the social system components, such as institutions, practises, and culture. Designers are thus required to view and design a DSS as a socio-CPS, which is combined by digital, physical, and social systems. By considering the components of social systems and their impacts from the initial stages of the design process, designers can derive socially acceptable design solutions.

However, methods to design a DSS architecture (i.e., system components and their relations) by comprehensively considering the three perspectives of digital, physical, and social systems have not been established. Specifically, the previous studies described in Section 2.2 have the following limitations, which are summarised in Table 1:

- In the previous DSS design studies actively conducted on smart PSSs and in the related areas, the main focus has been on the integration of digital and physical systems. Therefore, methods to design a holistic structure of a DSS that includes social system components have rarely been discussed. An exception is Akasaka et al. [11], who proposed a method for deriving a vision for a DSS based on three perspectives, namely digital, physical, and social perspectives. However, the scope of the design method only includes DSS visions and its abstract system concepts; it does not support the design of concrete DSS architectures.
- In the existing studies related to socio-CPS (or CPSS) modelling, the main focus is on the analysis of specific past or ongoing cases, and few studies can be found on the design methodology of socio-CPSs. Some exceptions, such as [41–43], have discussed the design method for socio-CPSs; their focus is, however, on the modelling schemes for integrating the different three dimensions of digital, physical, and social systems. Such studies have not presented the concrete design process, i.e., how designers use the modelling schemes for the design of DSSs.
- Looking beyond the smart PSS and socio-CPS fields, we can find some design approaches that explicitly include the social system perspective in their design process (e.g., the transition design and MDM). However, they present only abstract and conceptual design methodologies, not the specific design process and methods.

Table 1. Comparison of previous studies.

			Considering Three Perspectives of Digital, Physical, Social Systems	Focusing on DSS Architectural Design	Presenting Concrete Design Process and Method
Smart PSS and related areas	**Digital-physical system integration**	[23,26,33–37]	-	X	XX
	DSS vision design	[10]	XX	-	X
Socio-CPS modelling studies		[40–44]	XX	X	-
Others in design research field		[16,45]	XX	-	-

"XX": Covered, "X": Partially covered, "-": Not covered.

To address these research gaps, we propose a method for designing the DSS architecture based on the socio-CPS concept. Specifically, we developed a design process and frameworks that support designing the concrete DSS architecture by comprehensively considering the three perspectives of digital, physical, and social systems.

3. Research Approach

In this study, we address the following research question (RQ): what design method (design process and frameworks used therein) can support the design of DSS architectures comprehensively considering the three perspectives of digital, physical, and social systems in the context of solving social issues and realising social innovation? As the RQ indicates, the aim of this study is to develop a method for design support. Therefore, this study follows the principles of the general design research methodology (DRM) proposed by Blessing and Chakrabarti [46]. The DRM is widely accepted within the design research community. Specifically, this study pertains to the 'prescriptive study' phase in the DRM, which corresponds to the development of knowledge, guidelines, and tools for design support. Following the principles of the prescriptive study methodology in the DRM, this study adopts the approach shown in Figure 2.

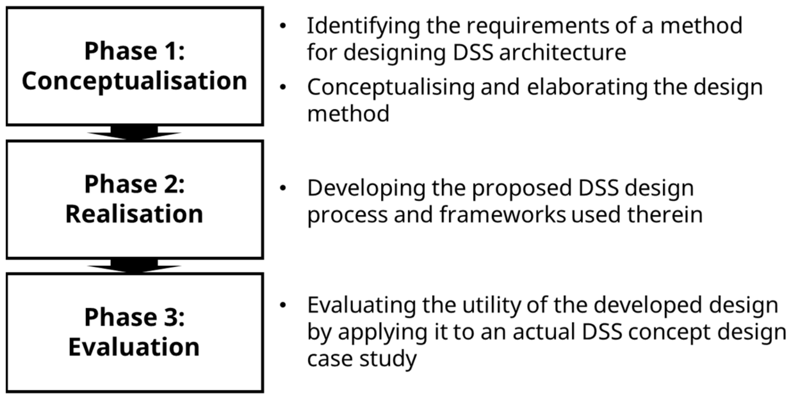

Figure 2. Overview of the research approach.

In the first phase of this study (Phase 1: Conceptualisation), we conceptualise a method for designing a DSS architecture that enables designers to comprehensively consider the three perspectives of society, digital, and physical domains. In doing so, we first clarify the required functionalities of the method and describe them as the requirements. This clarification of requirements is carried out through discussions among researchers based on the system concepts and design studies discussed in the previous studies in Sections 2.1 and 2.2. Subsequently, the overview of the design process and frameworks that meet the requirements is conceptualised and elaborated.

In the second phase (Phase 2: Realisation), the DSS design process and the corresponding frameworks employed are developed based on the conceptualisation results. We first identify the overall design process. Then, the design support frameworks used in each step are developed. In doing so, if the frameworks proposed in the previous studies can be utilised, we refer to and expand them as necessary. Meanwhile, for scopes that have not been addressed in previous studies (e.g., configuring the DSS architecture based on the socio-CPS concept), we develop new frameworks through discussions based on past design experiences and surveys of related methods. Finally, we identify the detailed design process, in which multiple design frameworks can be used smoothly in terms of their input–output relationships.

In the final phase (Phase 3: Evaluation), the utility of the developed design method is evaluated by applying it to an actual DSS design case. In this study, we focus on a design case study of a smart mobility service in a smart city in Japan, in which some of the authors were involved. The reasons for selecting the case are as follows: first, it fits the context of this study, namely the design of DSSs to solve social issues. Second, the authors have easy access to various data and information. Third, the design target addressed in the case (i.e., smart mobility services) is appropriate as a case to evaluate the developed method since it requires the comprehensive consideration of three perspectives of socio-CPSs, namely physical systems (e.g., mobility vehicles and urban physical infrastructures such as roads), digital systems (e.g., data obtained from vehicles and digital systems for analysing the data), and social systems (e.g., residents' acceptance of new vehicles and rules for using them on public roads).

The results of the method conceptualisation and development are described in Section 4. The conceptualisation results are explained in Section 4.1, and the developed design process and frameworks are described in Section 4.2. The results of the case study for evaluating the method are described in Section 5.

4. DSS Design Method Based on the Socio-CPS Concept

4.1. Conceptualisation

4.1.1. Requirements

Based on the analysis of existing studies and the research gaps described in Section 2, we identified the following three requirements for the DSS design method (which include the social system domain in the design space):

- (i) Simultaneous and comprehensive consideration of the three different domains of social, digital, and physical systems.

As argued in the concepts of socio-CPSs [14] and CPSSs [32], denoted in Section 2.3, considering the three different domains of social, digital, and physical systems is important to realise the social implementation of digital technologies and social innovation. Therefore, the design method proposed in this study requires a framework for DSS architectural design that enables designers to simultaneously and comprehensively consider three different domains, namely social, digital, and physical domains.

- (ii) DSS design process that commences with 'future vision' rather than focusing on technological seeds or user needs.

This study aims to address social issues and achieve social innovation beyond the scope of individual technological development and the fulfilment of needs. As argued in the transition design study described in Section 2.2.3, one important approach for designing social innovation is the 'backcasting' approach, which involves developing and implementing design solutions (e.g., technologies, systems, and services) based on 'future visions' that represent the desired societal outcomes [45]. This 'backcasting' approach contrasts with the 'forecasting' approach, in which design solutions are generally designed and developed based on the 'extension' of existing technologies and user needs. Therefore, the method proposed in this study requires a design process that commences with the 'future vision' rather than technological seeds or user needs.

- (iii) Considerations of values co-created among various stakeholders involved in a DSS.

As noted in Section 2.1.1, service systems (including DSSs) strive to achieve 'value co-creation' among various stakeholders. Therefore, DSS designers should consider not only its 'system structure' aspects (e.g., the components and their relationships in the social, digital, and physical system domains) but also the 'value structure' aspects, which correspond to the overview of co-created values. Therefore, the proposed method requires a framework that enables designers to analyse the values co-created among various stakeholders and incorporate them into the DSS design.

4.1.2. Concept

Based on the three requirements mentioned above, we conceptualised the proposed DSS design method, as illustrated in Figure 3. The overall view of Figure 3 indicates that DSS designers initially identify the (future) 'visions' to be realised. Subsequently, a 'DSS architecture' is constructed based on the identified vision. This vision-oriented design process corresponds to Requirement (ii). For the DSS architecture, the proposed method uses two design models, the component structure model (CSM) and value network model (VNM). The CSM is used to structurally describe the components in three different system domains, namely social, digital, and physical domains. The CSM modelling approach is theoretically grounded in engineering design or the systems engineering approach. It involves systematically describing complex design objects using multilayered models. The CSM corresponds to Requirement (i). The VNM is a design model that provides an overview of the values co-created among various stakeholders in a DSS; therefore, it corresponds to Requirement (iii). This model is inspired by the customer value chain analysis (CVCA) method [47], which enables designers to analyse and articulate the values exchanged between various stakeholders.

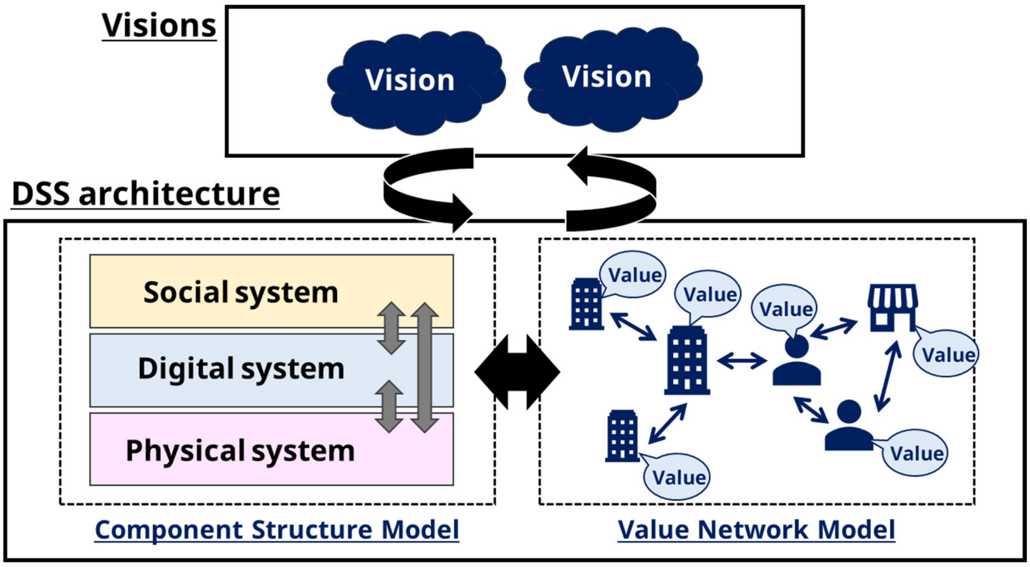

Figure 3. Conceptual overview of the proposed DSS design method.

In this research, the term 'model(s)' corresponds to the design models for functional modelling in the conceptual design phase; they are used to represent how the general goal of the system is achieved through the realisation of subgoals within the system [48]. Therefore, functional modelling depicts the structure of system components to achieve its general goal. They are thus not the executable models, such as those used in model-based systems engineering, which enable computational simulation and traceability management in the design process [49]. Eisenbart et al. [50] have analysed various approaches to functional modelling and found various perspectives on 'what to represent' in functional modelling. According to their analysis, the functional modelling perspectives include the 'technical system allocation', which means the representation of components of a technical system to achieve requirements, and the 'stakeholder allocation', which means the representation of the roles of various stakeholders [50]. The CSM mentioned above refers to the 'technical system allocation', as it illustrates the relationship between the system goals and the components in the digital, physical, and social domains. Although the term 'technical system' is not appropriate in this study because it also includes the social systems, we use it to cite previous studies. Meanwhile, the VNM corresponds to the 'stakeholder allocation' in functional modelling.

4.1.3. Scope

The scope of this study is the conceptual design stage of the DSS architecture. Namely, the proposed method focuses on identifying the system goals (problems to be solved) that the DSS should achieve and configuring the conceptual functional models to achieve the goals. Therefore, more detailed design performed after the conceptual design (e.g., prototype design and development, user testing, social experiments) are not included in the scope of this study.

4.2. Design Process

Figure 4 presents an overview of the proposed design process. The process consisted of four steps, which were context analysis, future-life visioning, vision-based concept design, and architectural design. As indicated by the feedback loop between Steps 2–4 in Figure 4, this design process is performed as an iterative procedure.

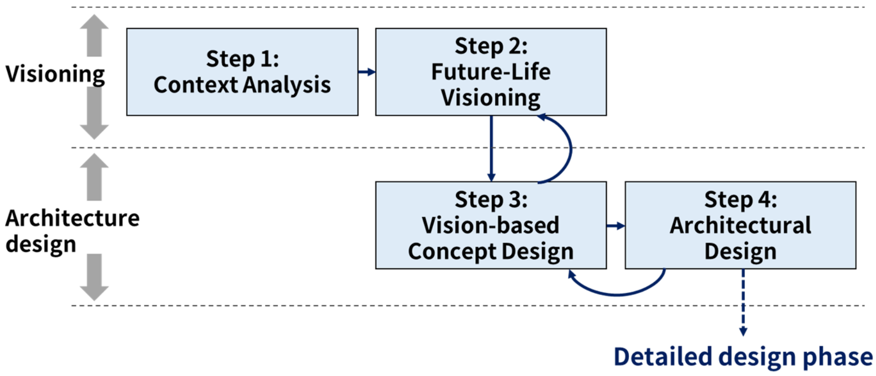

Figure 4. Proposed design process.

The first two steps correspond to the 'visioning' stage, and the latter two steps correspond to the 'architecture design' stage. The proposed design models (i.e., the CMS and VNM) conceptualised in Section 4.1. are mainly used in 'Step 4: Architectural Design', which is the most important step for DSS architecture design. The other steps (i.e., Steps 1–3) are composed of the design process and frameworks based on the authors' previous work (e.g., [11]), which are improved to connect with the context of DSS architecture design, the main focus of this study. Thus, the novelty of the proposed design process is that it presents a consistent design process and frameworks that can seamlessly connect various design activities from future vision creation to system architecture design in the context of DSS design based on the socio-CPS concept.

The details of each step are explained in the following sections.

4.2.1. Step 1: Context Analysis

The proposed design process commences with a multi-perspective context analysis of the target field (i.e., city or region). This step aims to perform a macroenvironmental analysis from a wider perspective than a micro-analysis of individual digital technologies and user needs. The analysis results serve as key inputs for Step 2, in which the future-life vision is depicted.

Several analytical frameworks support this contextual analysis. Akasaka et al. [11] developed a framework called the digital future hexagon (DFH) to conduct this analysis from the three perspectives (i.e., social, digital, and physical) of the socio-CPS. The framework is shaped as a hexagon that supports designers in analysing urban situations and contexts from the following six perspectives: cities, citizens, digital systems, data, physical products, and urban resources. The first two perspectives correspond to the social domain, the next two to the digital domain, and the final two to the physical domain. The DFH encompasses both digital and physical domains, making it a valuable framework for projects that require designers to consider the features or strengths of various digital technologies and the digital/physical urban infrastructure.

Other widely recognised environmental analysis frameworks can also be effectively used in this step. For example, the PEST analysis method [51], a method for analysing the external environment from the perspectives of political, economic, sociocultural, and technological factors, is also useful. Frameworks that extend the PEST, such as the STEEP analysis method [52], which adds an ecological/environmental perspective to the PEST and the PESTEL analysis method [53], which adds ecological/environmental and legal perspectives, can also be used effectively depending on the project objectives and focuses. Furthermore, SWOT analysis, which analyses the environment from four perspectives—strengths, weaknesses, opportunities, and threats—is another option. In contrast to the PEST analysis, which solely focuses on the external environment, the SWOT analysis includes both the internal and external environments within the scope of the analysis. An overview and analytical perspectives of the aforementioned methods are summarised in Table 2. DSS designers can select analysis frameworks that fit their design projects based on this type of summarisation.

Table 2. Various methods to support the context analysis.

Method	Overview	Analytical perspective
PEST	PEST and its related analyses (such as PESTEL and STEEP) are external environment analysis methods for conducting strategic analyses or market research from a macro-analytical perspective. They provide various macro-environmental factors to be considered in the analysis.	Political, economic, socio-cultural, and technological factors
STEEP		Ecological/environmental factors in addition to PEST
PESTEL		Ecological/environmental and legal factors in addition to PEST
SWOT	SWOT is an environmental analysis method that focuses on both the internal (i.e., strengths and weaknesses) and external (i.e., opportunities and threats) environments of a company or an organization.	Strengths, weaknesses, opportunities, and threats
DFH (Digital Future Hexagon)	DFH is a context analysis method of a city or region that focuses on the three perspectives of the socio-CPS (i.e., social, digital, and physical domains). This method is valuable in projects where designers need to consider the features or strengths of the digital technologies to be applied and the digital/physical urban infrastructure in the context analysis. It explicitly includes digital and physical domains.	Social (e.g., cities and citizens), digital (e.g., digital systems and data), and physical (e.g., physical products and urban resources) perspectives

In Step 1, DSS designers conduct context analysis employing the aforementioned methods using data collected via questionnaires, interviews, and fieldwork as inputs. By conducting this analysis, designers can gain valuable insights that serve as 'signs' for envisioning desirable future lives associated with the specific focus of their project. The results of this analysis will be an essential input for the visioning process in Step 2.

4.2.2. Step 2: Future-Life Visioning

In this step, DSS designers create images of the desired future lives and visualise them as 'future visions'. Designers begin by conducting a brainstorming session to envisage and generate ideas for the desired future-life images using the outcomes of Step 1 as inputs. Note that the visions created here should focus on future lives or citizen experiences and not on technologies or services. The findings in Step 1 typically encompass various perspectives. For example, when using the DFH method, the findings often include three different perspectives, namely social, digital, and physical perspectives. Therefore, during the brainstorming session, the 'forced association' method is employed to ideate the future visions. This method involves combining information and concepts from different domains to inspire and generate new ideas. It is useful for integrating different perspectives and creating innovative ideas for future visions [54]. This visioning process should be undertaken as a 'divergent process' that focuses on generating as many ideas of future lives as possible to investigate various possibilities. As Dunne and Raby [55] assert in their study on speculative design, the divergent exploration of various levels of possibilities, encompassing not only 'probable' future lives but also 'plausible' and 'possible' future lives, holds great significance. Following the divergent ideas on the desired future lives, the design team selects some of the ideas by voting and having discussions. The selected ideas are then visualised as 'future-life snapshots' using the worksheet displayed in Figure 5a. Subsequently, to clarify the overall direction of future-life images, designers summarise the snapshots to establish a single overarching future vision using the worksheet depicted in Figure 5b.

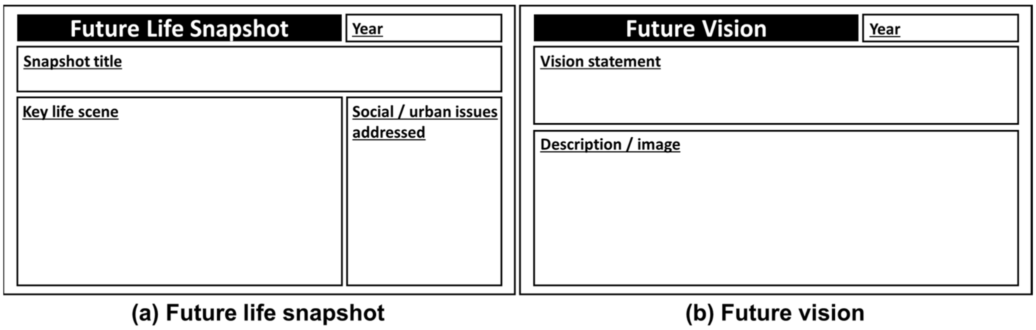

Figure 5. Worksheets for future-life visioning.

In this study, by using this technique, designers generate and visualise future visions from the perspective of desirable future lives and citizen experiences. This focus differs from existing approaches that include the visioning process. For instance, this visioning process focuses more on citizens' lives and experiences than the technocentric approach to future visioning, such as technological roadmapping, which strongly focuses on the future of technological systems and services. In addition, it differs from the existing social visioning process often used in the field of policymaking, which focuses on more abstract levels, such as the overall direction of society. The key feature of the proposed visioning process is its focus on future lives or citizen experiences. This enables designers to incorporate the 'human-centricity' concept more strongly into DSS design.

4.2.3. Step 3: Vision-Based Concept Design

In Step 3, designers develop the DSS concept by utilising the outcomes of the future visioning process in Step 2. Designers initially explore the 'key functions' that the DSS should provide to achieve the future-life snapshots identified in Step 2. In design studies, a 'function' is essentially regarded as a symbol that represents the action of 'doing something' [56]. In other words, a function is an abstract concept that represents what a system or service performs for other actors (e.g., users, citizens, and relevant organisations). Therefore, the function is often used as a central concept in conceptual design [56]. In this study, the DSS concept is represented as a set of key functions.

After identifying key functions, the relationships between the identified functions and future-life snapshots are hierarchically modelled using a design model called the vision life function model (VLF model), as illustrated in Figure 6. This type of multilayered model supports designers in associating design elements at different levels of abstraction (e.g., vision and function). Furthermore, it encourages logical and systematic thinking because the relationship between means and ends is explicitly described.

When using the VLF model, the thinking process of designers initially follows a top-down approach, that is, from the upper-layer elements (i.e., future vision and future-life snapshots) to the bottom-layer elements (i.e., key functions). However, the vision or life snapshot must be updated or modified by reviewing the relationships between elements from the opposite (i.e., bottom-up) direction if required. The iterative process of alternating between the abstract and concrete layers is crucial for designers to perform a more exhaustive exploration.

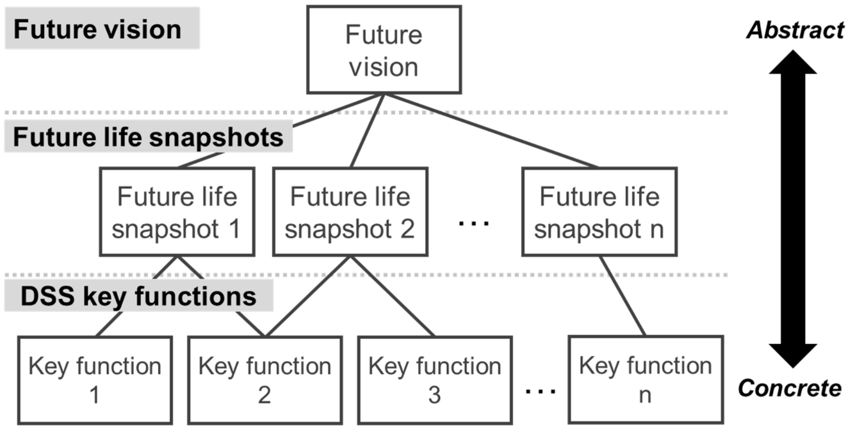

Figure 6. Vision life function (VLF) model.

4.2.4. Step 4: Architectural Design

In Step 4, DSS designers develop models of DSS architecture through the lens of a socio-CPS, based on the concept created in Step 3. As mentioned in Section 4.1.2, this study proposes two design models for this architecting, the CSM and VNM.

- Component Structure Model (CSM)

The CSM is a design model that delineates the components of a DSS and their relationships in the social, digital, and physical domains. An overview of the CSM is presented in Figure 7. The CSM consists of ten layers, namely institutions, culture, practises, economic structures, DSS key functions, data, digital systems, humans/organisations, physical resources, and other resources. As shown in Figure 7, nine of these layers, except for 'DSS key functions', are classified into the social, digital, and physical domains.

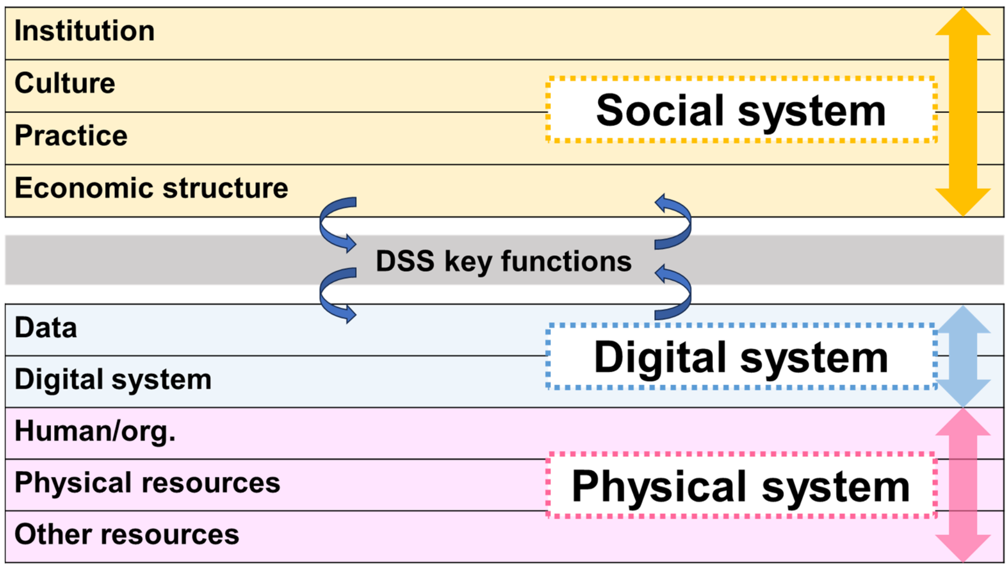

Figure 7. Component structure model (CSM).

In the social system domain, the first four layers are specifically defined as 'institutions' (rules, regulations, and power structures), 'culture' (the sum of norms and values that together constitute the perspective from which actors think and act), 'practises' (the sum of routines and behaviours), and 'economic structures' (markets, financing, consumption, and production). These four layers are derived from the discussion of social system components in socio-technical innovation by Ceschin [57]. The digital system components are conceptually modelled via two layers, the 'digital system' and 'data'. The digital system refers to technical systems that are not specifically visible to citizens or users as physical entities, such as apps, databases, and digital platforms. Data refer to digital data used as the input or output of the digital system. The physical system components are described by three layers, namely 'human resources' (individuals, groups of people, and organisations), 'physical resources' (tangible physical resources such as products and urban resources), and other resources (intangible resources such as knowledge and skills). This classification is based on service engineering studies that describe the physical components of a service using human and physical resources [58]. The 'other resource' layer is added based on the theory in the service dominant logic [16] that delineates intangible resources as important inputs for value co-creation [17]. The 'DSS key function' layer, which does not belong to the social, digital, or physical domains, is an abstract layer that conceptually links the above nine layers.

When using the CSM, DSS designers initially describe the key functions in the 'DSS key function' layer based on the outcomes of Step 3. Next, the components required to realise key functions are described in the digital (data and digital systems) and physical (human resources, physical resources, and other resources) domain layers. Subsequently, the social system elements for implementing the DSS are investigated and described in the layers of the social system domain (i.e., institutions, culture, practises, and economic structures). This multilayered framework enables designers to systematically design a DSS by simultaneously considering and interrelating the components in various layers. It is important to use this CSM collaboratively with various stakeholders, including companies, researchers, and municipalities. In such a collaborative design, the CSM facilitates effective co-design by integrating or summarising knowledge and information from various stakeholders into a single design model.

- Value Network Model (VNM)

The VNM is a design model for describing the values co-created among stakeholders in a DSS. This model visualises (i) stakeholders involved in a DSS (e.g., users, citizens, companies/organisations, and governments), (ii) tangible and intangible items exchanged between stakeholders (e.g., service functions, money, goods, and data/information), and (iii) each stakeholder's values co-created in a DSS. The VNM is an extension of the CVCA method [47] proposed in the product design field. In particular, the VNM allows for representing the values for each stakeholder in the same model in contrast to the CVCA, which only represents tangible and intangible resource flows, such as money, products, and information (Figure 8).

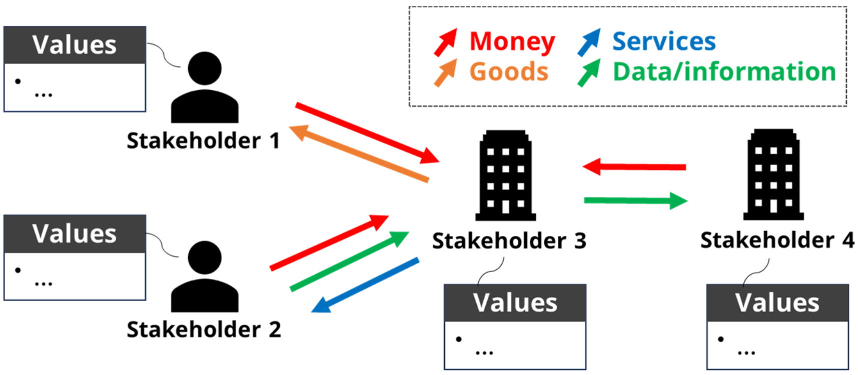

Figure 8. Value network model (VNM).

In describing a VNM, DSS designers initially list the different types of stakeholders (e.g., individuals, companies, non-profit organisations, and the government) involved in the DSS. The relationships among stakeholders are subsequently described as exchanging four resources, which are service functions, money, goods, and data/information. Subsequently, the perceived or experienced values of each stakeholder are extracted and added to the model. In this study, the value-mapping matrix (Figure 9) is used to extract the values. The vertical axis of this matrix represents the DSS stakeholders; the horizontal axis denotes the 'value scenario' and three types of value, namely 'short-term value', 'side effects', and 'long-term impacts'. The value scenario provides an overview of situations in which each stakeholder perceives value. 'Short-term values' correspond to the positive values that each stakeholder perceives within a single service transaction. As subcomponents of short-term values, we present four value types, encompassing functional, emotional, economic, and social values. This value classification model has also been used in the service value co-creation literature [59] and was originally proposed by Sheth et al. [60]. It supports value extraction, serving as a trigger to investigate various values for each stakeholder. 'Side effects' refers to the negative values that can be generated in a single service transaction. As Tsunetomo et al. [33] noted in their smart PSS design method, designers should consider the negative impacts of digitalisation, such as breaches of privacy, data bias, and other user risks. Therefore, this matrix includes a side effect column to encourage designers to consider the negative aspects inherent in DSS provision. The final column, 'long-term impacts', is used for describing the positive and negative values that can be generated as a result of the long-term relationship with users. One of the important benefits of digitisation and servitisation is the opportunity to build long-term relationships with users and use the data obtained through these relationships to add greater value to users through, for example, data-based customisation [10]. In addition, from the viewpoint of sustainable society development, scholars have discussed that servitisation is a means of dematerialised value creation [61]; thus, the environmental impacts of the long-term provision of a DSS should be considered in the design process. Therefore, designers should consider the positive and negative values created through the long-term provision of a DSS. These signify the reasons why the proposed matrix includes 'long-term impacts' within its horizontal axis. After exploring and extracting various values using this matrix, the designers finally add the extracted values to the VNM.

Stake-holders	Value perceived scenario	Short-term value (transactional) [Functional / Emotional / Economic / Social]	Side effects (transactional)	Long-term impacts [+, -]
Stake-holder 1				
Stake-holder 2				
...				

Figure 9. Value-mapping matrix.

4.2.5. Design Iterations

Throughout the design process, from Steps 1 to 4, designers return to the previous steps to modify and update the design models as required. This iterative design process is important to construct a more comprehensive and sophisticated DSS architecture. Moreover, the iterative process effectively achieves consensus on design outputs among the stakeholders involved in the DSS design.

5. Case Study

5.1. Overview

In this study, the proposed design method was applied to an actual DSS design case to demonstrate its utility in supporting DSS designers. The case was a project aimed at creating a smart mobility service in Kashiwa-no-ha Smart City, one of the leading smart cities in Japan. Various initiatives have been implemented in the Kashiwa-no-ha area to develop advanced smart mobility-related technologies and services. These include projects involving on-demand buses, automated buses, and shared-cycle services. Within these initiatives, a design project was launched to create a smart mobility service for local citizens, particularly senior citizens.

In this case study, we assembled a design team comprising a service design researcher and technical researchers specialising in smart mobility technologies. This project was promoted through a collaborative design approach involving various stakeholders, such as a real estate company, a non-profit organisation working on urban planning and community development, a municipality, university researchers specialising in advanced mobility technology, and a shopping centre in the area. They were involved in several aspects of the design process and engaged in collaborative discussions, meetings, and ideation workshops.

The project started in September 2021. The first 2 months were dedicated to holding the kickoff meeting and to building relationships with relevant local stakeholders. In November 2021 and January 2022, we conducted large-scale questionnaire surveys and fieldworks to investigate the current situation of the local mobility in the area; based on the data obtained and the analysis results, we conducted a context analysis, which corresponds to Step 1. After that, we held several sessions for Step 2, future-life visioning, and Step 3, vision-based concept design, from March to April 2022. In practise, Steps 2 and 3 were iteratively carried out, with the above-mentioned local stakeholders participating in the discussions and meetings. In May 2022, we designed the DSS architecture (i.e., Step 4: Architectural Design); in this step, the visions and DSS concepts determined in the previous steps were updated if necessary. The details of our activities are explained in the following section.

5.2. Case Study Results

5.2.1. Step 1: Context Analysis

In this case, we first conducted large-scale questionnaire surveys and fieldwork to gather important data on the current mobility situation in the area. The questionnaire surveys were conducted twice, in November 2021 and in January 2022. The first survey was held in November 2021 in the form of a web-based questionnaire. The second was conducted by posting questionnaires to all households in the target area. The second survey was aimed at collecting more responses and opinions from residents living near the city centre. These data included the destinations that residents often visit, the means of local transportation they use in their daily lives, and their needs and problems associated with local transportation. Furthermore, we conducted discussions with companies and non-profit organisations promoting urban planning in this area to identify the city's vision, policies, and urban resources associated with mobility. We also had several opportunities to discuss the latest technologies and digital data that should be considered in this project with technological researchers both inside and outside the project team.

This project aimed to create new mobility services that use digital technologies to solve urban issues. Therefore, we applied the DFH framework, which included both social (or urban) and digital domains, from an analytical perspective. In the context analysis using the DFH, each space in the hexagon was filled based on the results of various surveys and discussions. Subsequently, we developed various hypotheses regarding opportunities for future lives, which correspond to the central part of the hexagon. This was achieved through a divergent thinking process. In this case study, we employed the forced association method to generate ideas on opportunities for future lives regarding local transportation. Subsequently, we organised several meetings with local stakeholders who had worked on urban planning in the area to improve and update the hypotheses. An image of the DFH analysis results and a list of the extracted 'opportunities or indicators of future lives' are displayed in Figure 10.

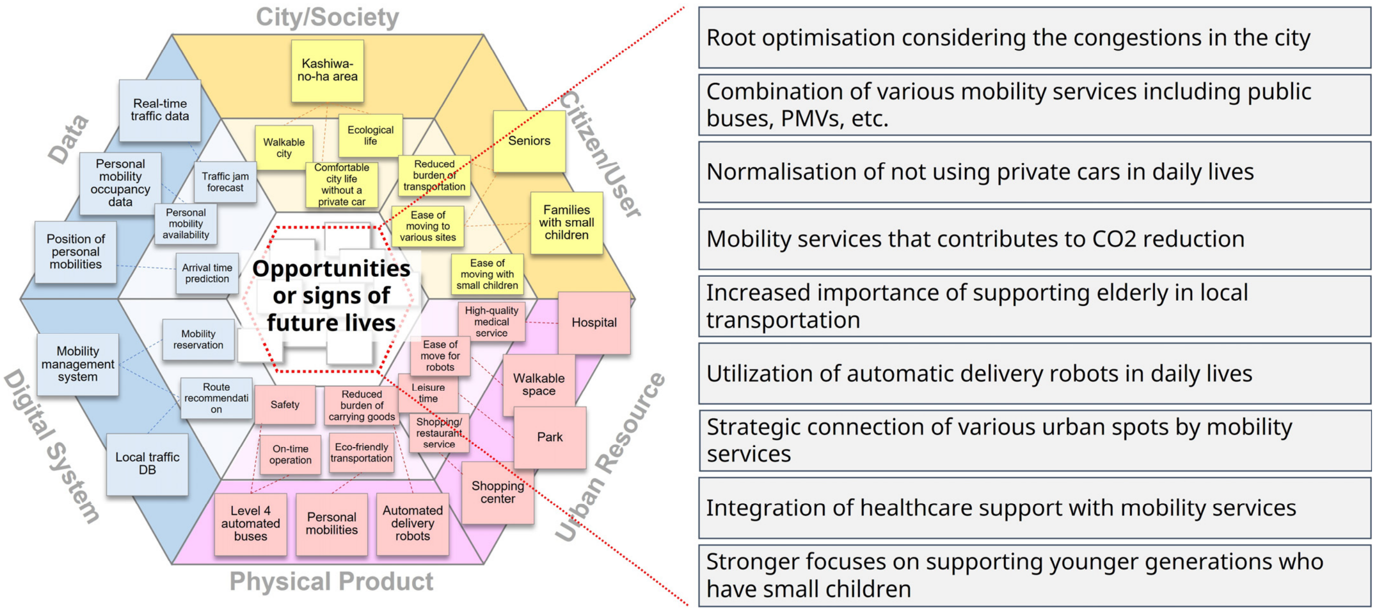

Figure 10. Results of the context analysis and extracted opportunities for future lives.

5.2.2. Step 2: Future-Life Visioning

In this step, we ideated the desired future lives on local transportation based on the opportunities identified in Step 1. We then visualised some of them as 'future-life snapshots'. In this case study, three ideas of future lives were visualised as snapshots, which were a 'lifestyle in which individuals can comfortably navigate without the need for private cars', 'experiences in which mobility services and other urban services are seamlessly integrated', and 'future lives in which objects are transported in accordance with the schedules of citizens'. These snapshots were generated based on a careful analysis of the context of the Kashiwa-no-ha area, taking into account factors such as the geographical situation, in which residential areas where many senior citizens live are far away from areas where many shops (e.g., supermarkets) and restaurants are concentrated.

Subsequently, based on these three snapshots, we defined an overarching future vision, namely 'a city where all people can share a higher quality of urban life by integrating mobility and other urban services'. The results of visualising and structuring future-life snapshots and an overarching vision are presented in the upper two layers of Figure 11.

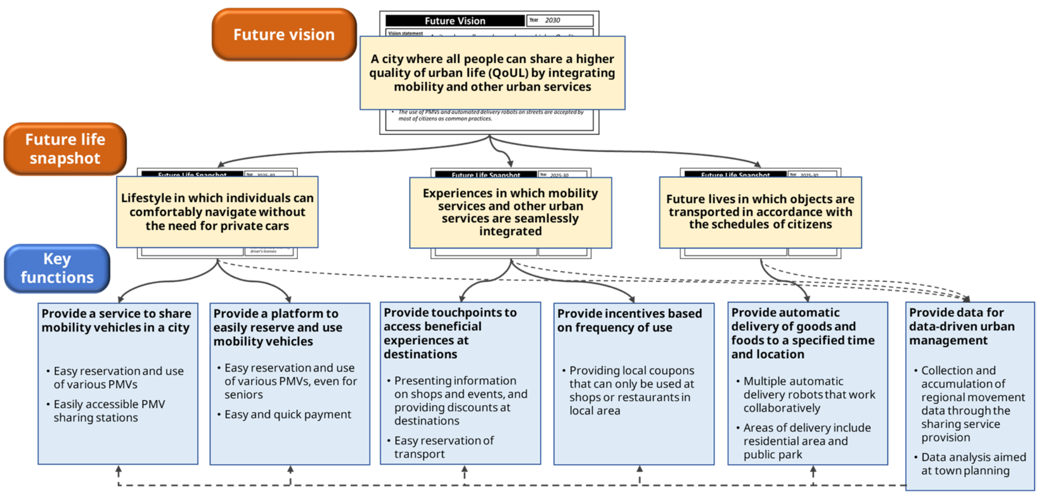

Figure 11. VLF model created in the case study.

5.2.3. Step 3: Vision-Based Concept Design

In Step 3, the key functions of the DSS to realise the future-life snapshots illustrated in Step 2 were identified. First, we investigated the key functions based on the structural model of future vision and future-life snapshots generated in Step 2. Consequently, six key functions were identified, as shown in the bottom panel of Figure 11. Subsequently, by employing the VLF model, a convoluted thought process was utilised to establish a connection between the three layers (i.e., future vision, future-life snapshots, and key functions). In this case, one of the six key functions, namely 'provide data for data-driven urban management', was not directly connected to any of the three snapshots. This was because it served as a mechanism to realise a sustainable business model for the DSS; its purpose was to support the continued provision of the other five key functions. Therefore, in Figure 11, this function is not directly associated with the snapshots.

Subsequently, the details of each key function were documented, and collaborative discussions were conducted with various stakeholders in the area. Through these discussions, we collected additional ideas and comments to update and revise the future vision and key functions.

5.2.4. Step 4: Architectural Design

In Step 4, the DSS architecture was designed using the CSM and VNM. In this case, the design team first created a CSM based on the DSS concept. The design team put the DSS key functions identified in Step 3 on the 'DSS key functions' layer of the CSM. The digital domain components (i.e., data and digital systems) and physical domain components (i.e., humans or organisations, physical resources, and other resources) used to realise the key functions are then described in the corresponding layer. Subsequently, the social system components were explored from the perspectives of institutions, culture, practises, and economic structures. The results of the CSM development are shown in Figure 12.

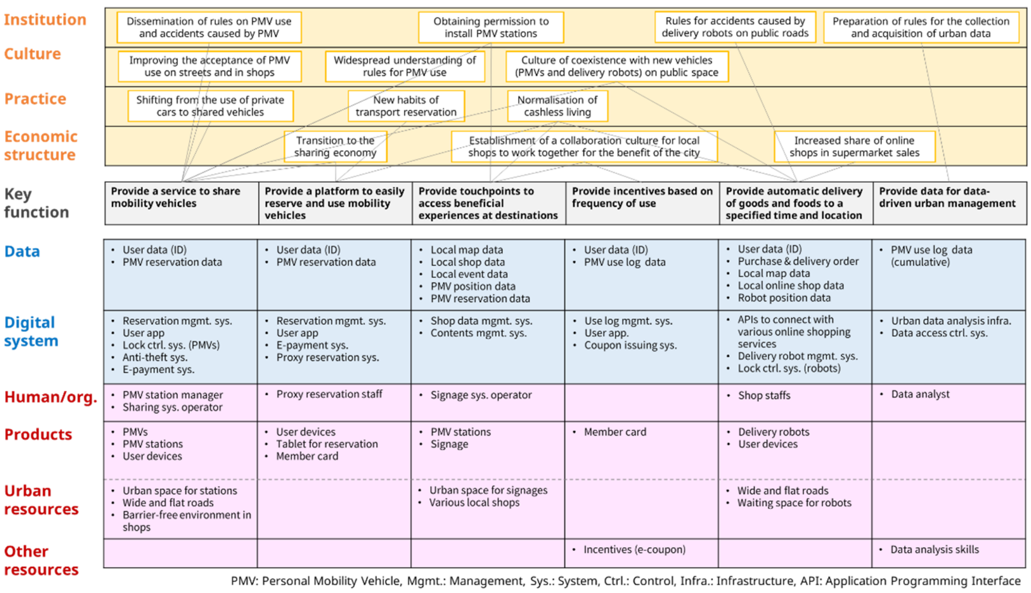

Figure 12. CSM created in the case study.

After developing the CSM, the design teams created a VNM to visualise the values co-created in the DSS. The design team initially listed the stakeholders involved in the DSS. These included local shops (e.g., supermarkets), local mobility service providers, urban developers, and municipalities. The tangible and intangible resources exchanged among these stakeholders were described as the flows of service functions, money, goods, and data/information (Figure 13). For the ease of readers' understanding, the 'local mobility service provider' was divided into two sub-divisions, namely the 'personal mobility vehicle (PMV) sharing service provider' and the 'automated delivery service provider'. The actor termed 'local shops' was also divided into 'real shops' and 'online shops' based on the difference in the service form. Subsequently, the values perceived by each stakeholder were analysed and extracted using a value-mapping matrix. The results are presented in Table 3. As shown, various types of values (e.g., functional, emotional, economic, and social) were extensively investigated in the 'short-term value' column. Finally, the extracted short-term values were graphically added to the VNM, as shown in Figure 13. The described VNM enabled us to comprehensively understand what resources were exchanged among stakeholders and what value could be co-created among them.

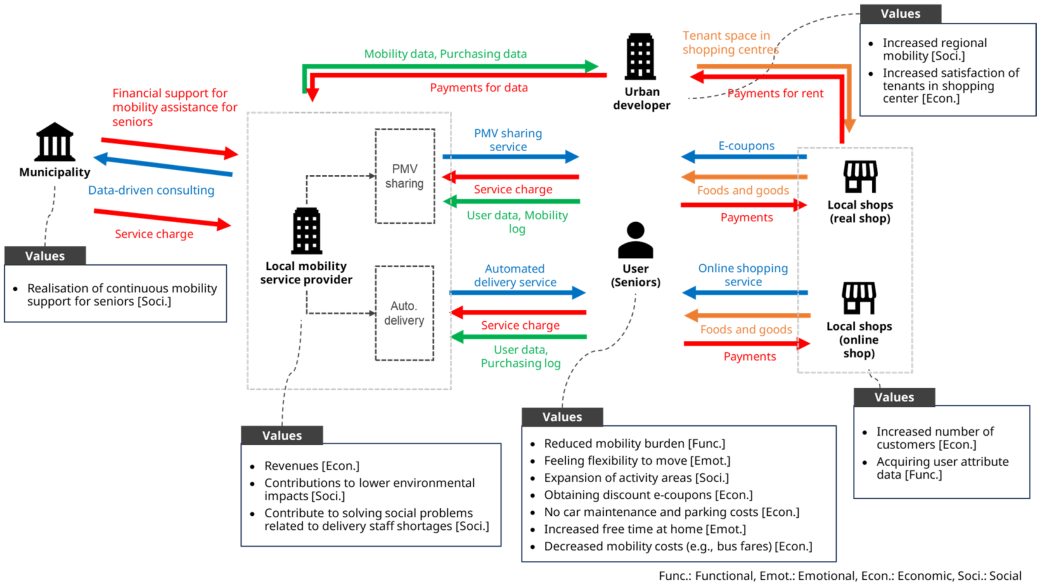

Figure 13. VNM created in the case study.

Table 3. Value-mapping matrix in the case study.

SHs	Value Perceived Scenario	Short-Term Value (Transactional) [Func./Emot./Econ./Soci.]	Side Effects (Transactional) [Side Effects to Whom?]	Long-Term Impacts [+, −]
Users (seniors)	Users can use a PMV to visit local shops at the time of their choice with low burden of transportation.	• Reduced mobility burden [Func.] • Feeling flexibility to move [Emot.] • Expansion of activity areas [Soci.] • Obtaining discount e-coupons [Econ.] • No car maintenance and parking costs [Econ.]	• Accident risks due to driving errors [U, LS, UD, M] • Embarrassment of being seen by surrounding citizens [U] • Anxiety in using an app for reservations [U]	• Positive impacts on health due to increased outings and social activities [+] • Decreased opportunities for physical exercise (e.g., walking) [-]
	Users can receive online-purchased goods and food at home, with more detailed arrival time settings than typical online shopping services.	• Reduced mobility burden [Func.] • Increased free time home [Emot.] • Decreased mobility costs (e.g., bus fares) [Econ.]	• Anxiety in using online shopping apps [U] • Decreased opportunities of outings [U, M]	• Negative impacts on health due to decreased outings and social activities [+] • Realisation of a convenient business format for families with dual income [+]

Table 3. *Cont.*

SHs	Value Perceived Scenario	Short-Term Value (Transactional) [Func./Emot./Econ./Soci.]	Side Effects (Transactional) [Side Effects to Whom?]	Long-Term Impacts [+, −]
Local shops (goods and foods)	Possibilities of attracting customers who did not come before are increased.	• Increased number of customers [Econ.] • Acquiring user attribute data [Func.]	• Accident risks inside shops [U, LS, UD, M] • Complaints from other customers [LS, PMVS, UD, M] • Risk of malfunctions in online shopping systems [U, PMVS, LS]	• Negative impacts on safety due to increased number of PMVs used inside shops [-] • Impact of enhanced online shopping on bricks-and-mortar operations [+/−]
Local mobility service provider	A new business based on PMV sharing can be realised if users are continuously acquired.	• Revenues [Econ.] • Contributions to lower environmental impacts [Soci.]	• Complaints from other customers [LS, PMVS, UD, M]	• Continuous acquisition of regional mobility data and realisation of data business [+]
	A new business based on automated delivery can be realised if users are continuously acquired.	• Revenues [Econ.] • Contribute to solving social problems related to delivery staff shortages [Soci.]	• Risk of malfunctions in online shopping systems (operated by each shop) [U, PMVS, LS]	• Continuous acquisition of regional purchasing data and realisation of data business [+]
Urban developer	Activated regional mobility could lead to regional revitalisation.	• Increased regional mobility [Soci.] • Increased satisfaction of tenants in shopping center [Econ.]	• Accident risks due to driving errors [U, LS, UD, M] • Complaints from other customers [LS, PMVS, UD, M]	• Continuous acquisition of regional mobility data and its use for urban development [+] • Continuous acquisition of regional purchasing data and its use for urban development [+] • Maintain land prices by regional revitalisation [+]
Municipality	A city that is mobility-friendly for all can be realised.	• Realisation of continuous mobility support for seniors [Soci.]	• Accident risks due to driving errors [U, LS, UD, M]	• Continuous acquisition of regional mobility data [+] • Both positive and negative impacts on health [+/−]

Func.: Functional, Emot.: Emotional, Econ.: Economic, Soci.: Social, +: positive, -: negative, SHs: Stakeholders. U: Users, LS: Local shops, PMVS: Local mobility service provider, UD: Urban developer, M: Municipality.

Finally, the design team reviewed the CSM based on the VNM and value-mapping matrix. This review process was important for redeveloping the model by adding missing components. For example, in this case application, elements such as 'accident risks due to PMV driving errors' were described in several 'side effect' columns in the value-mapping matrix. Therefore, the design team realised that they should update the layers in the social system domain and added the element 'dissemination of rules on […] accidents caused by PMV' to the 'institutional' layer of the CSM. The CSM and VNM, depicted in Figures 12 and 13, respectively, are described through this iterative process.

6. Discussion

In this section, we discuss the utility and limitations of the proposed method based on the case study results. The utility is discussed in terms of the three requirements mentioned in Section 4.1.1.

6.1. Simultaneous and Comprehensive Consideration of Social, Digital, and Physical Domains

Engineers and researchers developing DSSs are now obligated to carefully consider the legal and ethical aspects of the digital technologies used in these systems [33]. In addition, they should consider the methods for promoting social activities to realise the social implementation of DSSs, such as defining rules and laws associated with using DSSs and improving user acceptance. However, in general, such activities to prepare or create social system components are very broad and diverse; thus, it is not easy for designers to explore and identify them effectively. Furthermore, at the beginning of this case study, we faced difficulties in determining the scope of the design when we discussed the social activities required for the implementation of smart mobility services in the city. For such a challenging situation, in this case study, we used the CSM proposed in this study and discovered that it enabled designers to effectively explore and identify such social activities for DSS implementation. For example, in the application, designers could identify social activities such as developing rules for PMV use on public roads and organising events to increase the user acceptance of PMVs. The four lanes of institutions, culture, practises, and economic structures in the CSM served as stimulating inputs for designers to consider these social aspects. The four lanes of social system components cover a wider range than existing methods that represent social concerns related to socio-CPS realisation using the goal modelling method [41]; this indicated that the proposed method enabled designers to consider the social system components from a more comprehensive perspective.

Furthermore, the elements described in the 'side effect' column in the value-mapping matrix assisted in identifying a more extensive range of social activities to be implemented, as they depicted the potential risks of the designed DSS. These findings demonstrated that the proposed CSM was highly effective for facilitating designers when considering social activities for DSS implementation.

To comprehensively consider the different domains of social, digital, and physical systems, DSS design projects should be promoted as collaborative design projects with various stakeholders. In this case study, we thus organised several workshops and discussions with various stakeholders (e.g., technical researchers, urban developers, and municipalities) within the design processes. In doing so, we discovered that the proposed design models (e.g., the CSM, VLF, and VNM) were effective in structurally visualising and managing the results of multiple discussions and workshops in this long-term collaborative design process. In particular, these models were useful because they facilitated the gradual addition and systematic integration of the debated outcomes and the ideas generated during the process. This indicated that the proposed design models effectively facilitated a systematic co-creation process with various stakeholders and experts, which represented an advantage of the proposed method.

6.2. DSS Design Driven by the Desired Future-Life Visions

To achieve a socio-technical transition using digital technologies, the 'backcasting' approach is important, in which designers first define the future visions to be realised before designing the DSS concept [45]. In this approach, designers first define the future visions to be realised [45]; they then design the DSS functions and components to realise future visions. The important but challenging task in this backcasting-based DSS design approach is to consistently connect the abstract concept (i.e., future visions) and concrete component (i.e., DSS architecture). Regarding this point, the case study results showed that the proposed method supported a future vision-driven design approach. For instance, the VLF model effectively identified key DSS functions while associating them with desired future-life snapshots. In particular, it assisted designers in identifying key functions that had strong or consistent relationships with the upper-layer elements from various divergently generated functional ideas. This indicated that the VLF model supported the integrated consideration of two perspectives, namely the future vision and DSS functions. In addition, we also found that the combined use of the VLF model and the CSM was helpful for designers to holistically consider the overall relationship from the future visions to the specific DSS architecture. This especially supported the designers' thinking and discussion process to identify system components in the DSS architecture that are required to achieve the predefined future visions. This indicates that we established a design method that can connect various systems in different layers, which was discussed in the MDM study [15]; we therefore believe that the proposed method has important academic and practical significance.

We also faced difficulties in the combined use of the VLF model and the CSM. That is, such use of multiple models at different levels actually required a complex and iterative design process. In the case study, the whole DSS structure was not designed in a one-way direction from abstract elements (future vision) to concrete elements (functions, sub-functions, DSS architecture); rather, it required the design process to gradually and mutually concretise the vision and DSS architecture through an iterative process shown in Figure 4. To effectively promote this complex and iterative design process, we should develop a method for managing the traceability between the components of each model in our future research.

6.3. Consideration of Co-Created Values

The value-mapping matrix proposed in this study analysed the co-created values using a predefined value typology (i.e., short-term impacts, side effects, and long-term impacts). This presentation of value categories enabled DSS designers to comprehensively investigate and identify them from a broader perspective beyond their own limited expertise and bias. For example, as shown in the 'long-term impacts' column in Table 3, in the case study, the design team could discover that a PMV-sharing service to support local transportation had both positive and negative long-term impacts on the health of users. These complex impacts of value are difficult to determine when using a basic value analysis that strongly focuses on benefits or convenience for users.

Value is an important concept in developing smart PSSs [8]. Therefore, several studies have been proposed to support smart PSS design based on a comprehensive analysis of values (e.g., [8,33]). In contrast to existing studies, one of the distinctive features of this study is that the models for value analysis (i.e., the VNM and value-mapping matrix) and the DSS structure (i.e., the CSM) are associated with each other. This relationship between the design models is important for reviewing and updating previously described design models. In the case study, as mentioned in Section 6.1, the negative values described in the 'side effects' or 'long-term impact' columns were crucial when reconsidering or adding elements of the social system domain in the CSM. Therefore, providing comprehensive design support for DSSs based on both positive and negative values is the novelty of this study, which is also important for its practical utility.

Meanwhile, through the case study, we identified two practical challenges in the value analysis, described as follows: First, the comprehensiveness of the value lists filled in each column of the matrix depended on the designers' knowledge and experiences. A measure to address this challenge is to set up several opportunities for collaborative discussions with diverse stakeholders with different expertise, as we did in the case study. If we achieve such collaborative relationships, the range of knowledge that can be covered in a 'team' will be broader. Another measure to address the challenge is preparing a set of value items that can be used as input resources to use in the value-mapping matrix. The development of such a set of value items as a design support tool will be an important topic of our future research. The second challenge we found was the difficulty of including the perspective of environmental value in the value analysis. Before the case study, we assumed that environmental aspects would be considered when considering the 'long-term impact' column in the matrix; however, it did not happen in the case study. The reason for this was that the vertical axis of the matrix (i.e., stakeholders) did not include actors who were interested in environmental issues. For this challenge, we should improve the design process by adding a new rule that indicates the inclusion of a non-human actor such as the 'environment' to the value-mapping matrix.

6.4. Contributions and Limitations

6.4.1. Contributions

The novelty of the proposed method lies in its development of frameworks and a design process that can seamlessly connect various design activities, from future vision creation to system architecture design, in the context of DSS design based on the socio-

CPS concept. Particularly, in this study, we proposed new frameworks such as the CSM, VNM, and value-mapping matrix. Additionally, we proposed a DSS design process for utilising these frameworks while integrating our previous work [11]. Considering the above-mentioned perspectives, the unique usefulness and contributions of this study can be summarised in the following three points based on the discussions in Sections 6.1–6.3:

- The CSM and value-mapping matrix proposed in this study enabled the effective exploration and identification of the social activities necessary for the realisation of a DSS. Specifically, the four lanes of institutions, culture, practises, and economic structures in the CSM served as important inputs for designers to consider these social aspects. In addition, the 'side effects' column in the value-mapping matrix helped designers to consider the potential risks of the designed DSS and identify the social activities that should be implemented.
- The combined use of the VLF model and the CSM aided designers in identifying the functions and components in the DSS architecture while relating them to the visions of the desiresd future lifestyle. Particularly, an important contribution of this study is that the CSM supported the identification of not only the conceptual system model but also the DSS components and their relationship (i.e., DSS architecture) in the context of the vision-driven approach.
- The proposed value-mapping matrix enabled designers to explore and identify the values and impacts of the DSS from a broader perspective beyond their limited expertise and bias by presenting predefined value categories. Furthermore, by using the value-mapping matrix and the CSM mutually, designers can systematically review and update the design model from the perspective of co-created value.

6.4.2. Limitations

One of the limitations of this study was that it focused primarily on the conceptual design phase. This study does not provide detailed models or methods that can be used in the system development phase. Therefore, this study required a method to smoothly transition from the conceptual design to the development phase. Therefore, future studies should include the integration of modelling languages and related description tools, such as SysML [62] and UML [63], which are commonly utilised in system development.

Although this study proposed design models and processes, it did not encompass the development of practical tools (e.g., model-building software) that designers might employ in their projects. Therefore, to expand its application in the industry, developing designer support tools is also an important topic that should be investigated in future studies.

This research also has the limitation that the applicability of the developed method has not been sufficiently validated, as it was not applied to geographical contexts other than Japan. In this study, we assume that the proposed model is used to facilitate collaborative discussions among stakeholders. Such discussions are greatly influenced by the cultural context and factors of the city or region. For example, the power balance and human relationships in the city or region generally affect whether diverse stakeholders can discuss in flat relationships or not. Therefore, in our future research, we will apply the developed method to fields that have different geographical and cultural contexts from Japan and verify its applicability. In doing so, we would consider adopting design methods such as 'design games' to reduce the impact of hierarchical relationships between participants [64].

Another limitation is associated with support for the social implementation of DSSs. The scope of this study was limited to the modelling of the overall architecture of the DSS. Planning and visualising how to proceed with the process of social implementation were beyond the scope of this study. However, to realise the social implementation of a DSS, we must promote activities for social system transformation or updating. These activities include the development of relevant rules and fostering user acceptance of a DSS in parallel with the development of digital systems and physical products. To effectively promote such a complex development process, a 'roadmap' should be described that presents how, when, and what to do during system development [65]. Therefore, future research should also include a roadmapping method that supports designers in considering and describing how to develop a DSS.

7. Conclusions and Outlook

This study proposed a novel DSS design method that simultaneously considered three system domains, namely social, physical, and digital domains. Specifically, we developed design models (i.e., the CSM, VLF, and VNM) and a design process to support this DSS design. The case study results revealed that the proposed method was effective for considering components in the social system domain in addition to those in the digital and physical system domains in a DSS design. We also discovered that the proposed design models were valuable for enabling the systematic management of a long-term collaborative design process among various stakeholders to facilitate value-driven thinking in DSS design and support designers' consideration of various value propositions (both positive and negative) in a DSS. The practical contribution of this study can be summarised in three points discussed in the discussion section. First, the proposed method supports the simultaneous and comprehensive consideration of social, digital, and physical domains in DSS design. Second, the developed method was helpful for designers to holistically consider the relationship between the future visions and the specific DSS architecture. Third, the method supports DSS design based on various types of values co-created among DSS stakeholders. Furthermore, the theoretical contribution of this research is that we clarified a specific design method (i.e., a design process and framework) for designing the DSS architecture while relating the three different levels of systems (i.e., social, physical, and digital systems).

This study seeks to foster the development and application of digital technologies and services to solve various urban problems and contribute to the creation of sustainable societies and cities. Thus, this study contributes to Goal 9 ('Industry, Innovation and Infrastructure') and Goal 11 ('Sustainable Cities and Communities') of the 17 SDGs. In the sustainability research field, D'Adamo et al. [66] argue that through their analysis of the literature on the SDGs, social confidence and public involvement are crucial for sustainability efforts. The proposed method supports the design process that incorporates the social system perspective into DSS design and facilitates collaborative discussions among various stakeholders, including citizens. In this sense, this study contributes to the development of technologies and services for sustainability.

In future research, the proposed method should be applied to various DSS design projects to verify its generality. Moreover, as discussed in the discussion section, future research will include various topics for the improvement and extension of the proposed method. Regarding the improvement of the DSS functional modelling process, design methods to reduce the impact of hierarchical relationships among participants should be introduced. We also developed a method for managing the traceability between the models to effectively promote an iterative design process. To improve the value analysis, we will develop a set of value items that can be used as input resources to use in the value-mapping matrix. The value analysis process should also be improved by adding a rule to include a non-human actor, such as the 'environment', in the value-mapping matrix. Finally, to extend the proposed method to a more detailed design phase, modelling languages used in the detailed system development phase need to be integrated. We will also develop a method for supporting the roadmap development that describes how, when, and what to do for the social implementation of a DSS.

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