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THE NON-MATERIAL ASPECT OF ENGINEERING DESIGN: CONSTRUCTING AN ENGINEERING THINKING MODEL LED BY SERVICE DESIGN

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ABSTRACT
With the digital transformation of society, factors such as culture, emotions, experiences, meanings, values, and other non-material aspects are becoming central issues in current engineering design processes. The design objects in engineering are undergoing a transformation from tangible artifacts to intangible artifacts, yet the functional rationality engineering thinking models struggles to effectively engage in discussions concerning non-material aspects. This paper adopts a constructivist philosophical paradigm, rooted in the Contemporary Chinese design theory system, to review the development of service design in engineering activities and construct an engineering thinking model led by service design. The proposed engineering thinking model can improve and even resolve non-material aspects of engineering design issues, complementing traditional functional rationality engineering thinking model, guiding engineering design towards a more inclusive future transformation, and providing new perspectives and methods for progress in the field of engineering design.

Keywords: Service Design, Engineering Thinking Model led by Service Design, Engineering Design, Thinking Model, Non-material Factors

1 INTRODUCTION

Engineering is a deliberate human activity that creates artificial objects and realities using various resources and elements[1]. From the ancient ancestors of primitive societies constructing nests and dwellings to meet the survival needs of their clans, human history of creating social artifacts through engineering began[2]. Throughout history, from metallurgy and papermaking to water management, transportation, high-speed trains, airplanes, navigation, and aerospace, humans have created countless engineering marvels. Engineering has become a concentrated reflection of the essential forces of humanity, creating the material foundation of human society, charting the material progression of human civilization, driving changes in social structures, shaping the human spiritual world, and lifestyle.

Since the Industrial Revolution, emerging production technologies have driven changes in modes of production, leading to increasing specialization in engineering activities[3]. "Design" has become a crucial link in the integrated process of engineering concepts, design theories, design methods, and design knowledge[4], separating from implementation, operation, maintenance, and other steps in engineering activities. Engineers now unanimously agree that a design perspective must precede material creation activities, making engineering design the origin and source of social productivity development. The level of engineering design has become one of the decisive factors in a country's or region's comprehensive innovation and competitive capabilities.

Since its inception, engineering design has been influenced by the technical rationality of the Industrial Revolution, becoming one of the fields most influenced by a paradigm of rational problem-solving. This influence has led to the development of engineering thinking models characterized by functional rationality, adept at addressing material aspects of engineering problems such as materials, technology, structures, and functions. For example, Peter Checkland proposed functional decomposition and part-whole theory in engineering, focusing on analyzing the sub-functions of each part rather than the composition of the whole[5]. By identifying and analyzing sub-functions, Engineering designers can define the relationship between the functional parts of an engineering concept and the whole concept[6]. Herbert A. Simon suggested understanding and analyzing complex systems through a hierarchical structure. Complex systems can be divided into multiple levels, each with specific functions and

characteristics. Higher-level decision-making and control involve lower-level operations and execution, simplifying the analysis of complex problems[7]. Christopher Alexander emphasized the holistic nature of design, suggesting that architectural design should consider all components and their relationships, emphasizing the interaction between architecture, the environment, and society, advocating design as a holistic, organic process[8].

However, with the increasing refinement of material civilization, attention to tangible engineering is gradually diminishing, leading to a growing demand for service design in the engineering interaction process, with an increasing need for intangible experiences. Engineering design is undergoing a transformation from tangible artifacts to intangible artifacts. As Richard Buchanan pointed out, "The thing is important, but the halo around the thing is more interesting." [9] Non-material attributes such as culture, emotions, order, experiences, values, meanings, and other intangible aspects are becoming central issues in current engineering design processes. In the service economy era, engineering has been endowed with new values and meanings. Traditional tangible engineering projects alone cannot meet people's needs for engineering. Only when tangible engineering projects and intangible service design are organically combined can a complete engineering composition be achieved. However, the functional rationality engineering thinking models struggles to effectively engage in discussions concerning non-material aspects, resulting in current engineering designs inadequately considering user experiences and needs at the micro level, overlooking local cultural values and lacking humanistic care at the meso level, and failing to shape social structures and drive social development at the macro level.

The first Design Methods Conference held in London in 1962 marked the beginning of design research. Today, contemporary design research has broadened the scope of design. In contrast to traditional engineering design as a phase of engineering activities, design is now actively involved in all phases of engineering activities, focusing on complex socio-technical issues for the future. In 1984, Shostach proposed the design concept of combining tangible products with intangible services in "Designing Services That Deliver." [10] Subsequently, the concept of service design gradually emerged and began to be widely applied across various fields such as management and industry. Currently, academia generally considers service design emphasizes the understanding of the user's context, and requires its grasp of the holistic and systematic, and the ultimate output of meaningful results[11]. The introduction of service design provides a new perspective beyond technical rationality for understanding non-material aspects of engineering design discussions.

2 RESEARCH QUESTIONS

This paper aims to introduce the perspective of service design into engineering activities, construct an engineering thinking model led by service design, and shift from the material practices of traditional engineering design to the experiential practices of service design.

This research includes one primary research question and two secondary research questions.

[PRQ] How can service design thinking be integrated into engineering design to address contemporary challenges in engineering design at the levels of basic functionality, cultural experience, and social value, and promote a more comprehensive and sustainable future development of engineering?

[SQ1] How can we trace the evolutionary process of service design in engineering activities at different times, recognize the characteristics and roles of service design in engineering activities in different historical contexts, and then clarify the features and capabilities that contemporary engineering activities should possess in service design?

[SQ2] How can we construct a service design-led engineering thinking model and apply it to address non-material attribute issues in contemporary engineering design?.

3 THEORETICAL FOUNDATION

This research adopts the "Contemporary Chinese Design Theory System" proposed by Zou Qichang as the theoretical tool to understand phenomenon of service design in engineering activities, and thus provides guidance for the construction of engineering thinking model led by service design.

Zou Qichang's "Contemporary Chinese Design Theory System" is rooted in traditional Chinese design resources while incorporating advanced design experiences from around the world. It consists of three main systems: Meta Design Theory System, Parx Design Theory System, and Social Design Theory System, focusing on the fundamental concepts, basic thinking, basic categories, basic systems, core values, and other issues of the theoretical objects. The Meta Design Theory System studies the basic concepts and categories of the design object. The Parx Design Theory System addresses specific

design problems in the artificial world. The Social Design Theory System explores design order and social order.

Traditional engineering design often emphasizes material aspects such as technology and structures, while design led by designer focuses focus on non-material aspects such as humanity, culture, and society. Zou Qichang's theory connects basic functionality, cultural experience, and social value, facilitating the analysis of service design problems in engineering design from synchronic, historical, and morphological perspectives. It helps identify the reasons for intangible user experiences in engineering, understand the necessity of introducing service design into engineering, and better comprehend non-material aspects in engineering design phenomena. The basic framework of Contemporary Chinese Design Theory System as can be seen in figure1.

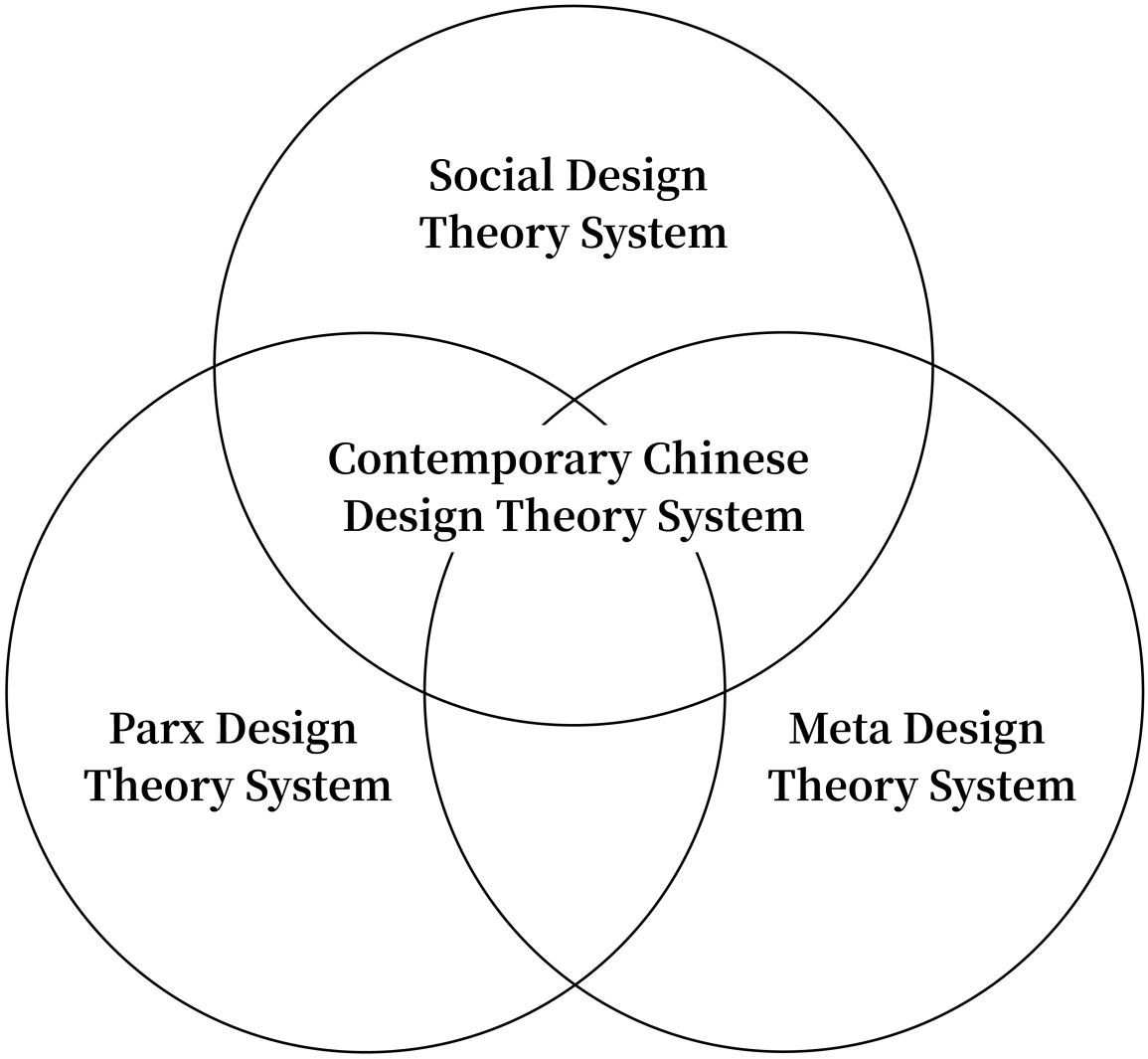

Figure 1. Basic Framework of the Contemporary Chinese Design Theory System

4 EVOLUTION OF SERVICE DESIGN IN ENGINEERING ACTIVITIES

In order to delve into the evolution of service design in engineering design and its impact across different periods, to gain a clearer understanding of the importance and necessity of service design in engineering design. We analyze the development trajectory of service design in engineering activities during the handicraft era, the industrial revolution era, and the digital age from a diachronic perspective, dissecting the characteristics and roles of service design in different historical contexts. This lays a more profound and comprehensive foundation for the subsequent construction of an engineering thinking model led by service design.

4.1 Service Design Issues in Engineering during the Handicraft Era

During the handicraft era, although service design did not exist explicitly in its modern concept, its essence and practices played a crucial role in engineering activities. While there were no dedicated service designers in the modern sense, craftsmen integrated the concepts of service design into their design work.

In the handicraft era, the main actors of service design were skilled craftsmen. Craftsmen emerged as technically specialized roles with the refinement of social division of labor. As early as the Paleolithic era, with the emergence of technical specialization, the identity of craftsmen was born. With the progress of human society, craftsmen evolved into an independent social group, inheriting rich experiential knowledge and mastering certain technical principles. During the handicraft era in engineering activities, craftsmen not only considered the basic functions of buildings in their design and implementation of engineering projects but also took into account the needs and experiences of users. This implies that engineering activities during the handicraft era already began to focus on the emotional and social values of the design objects.

Taking the garden engineering of ancient China as an example, these engineering activities not only provided spaces for daily living, but also reflected the owner's and aesthetic pursuits through landscape layout and architectural design. Craftsmen needed to consider adapting to the natural environmental factors of different seasons and climate conditions, continuously observing adjusting design schemes, and optimizing the garden to meet different functional and aesthetic needs at different areas. This diverse demand for practical functions, emotional value, and aesthetic pursuit precisely the vivid embodiment of service design in the engineering projects of the handicraft period.

Overall, although service design during the handicraft era did not have a modern clear definition, the core concepts of user-centricity, focus on experience and emotional value, and iterative and optimized design practices were already reflected and practiced. This laid a solid foundation for the subsequent development of service design in engineering.

4.2 Service Design Issues in Engineering during the Industrial Era

With the wave of the Industrial Revolution sweeping through society, the field of engineering design underwent significant changes. During this period, production shifted from traditional workshop craftsmanship to mechanized large-scale production. The scientific and technological inventions became the core drivers of engineering progress, accelerating the pace of industrialization. In this context, modern engineering design and the role of engineers emerged, fundamentally altering the role of service design in engineering.

During the Industrial Revolution era, the design protagonists in engineering shifted from craftsmen to modern engineers with defined professional identities and social status. With the specialization of engineering roles, the role of engineering designers began to emerge, specializing in design work. Since engineering activities often required collaboration among numerous technical personnel, engineers played a crucial role in service design, considering not only the technical implementation of engineering projects but also the social value and user experience of the projects.

The concept of service design saw further development and refinement during the Industrial Revolution era. Engineers began to realize that engineering activities not only took place in the natural environment but also aimed to create artificial environments suitable for human living. They focused on intangible artifacts such as social orders guided by engineering projects. Engineering designers needed to consider the social benefits of engineering projects based on design standards and regulations, transforming design concepts into concrete implementable solutions. During this period, engineering activities achieved the basic functions of engineering projects and began to explore usability aspects such as human-machine interactions.

4.3 Service Design Issues in Engineering during the Digital Age

Since the 19th century, the rise of industrial production has greatly propelled changes in the production methods of engineering design and the industrialization process of society. The ongoing Fourth Industrial Revolution we are experiencing is characterized by the deep integration of the internet and artificial intelligence. Engineering design is transitioning towards digitization, presenting more possibilities for service design in engineering.

In engineering design in the digital age, engineering projects have shifted from material to non-material attributes. Engineering designers need to collaborate with experts in technology, society,

management, and other fields for innovation, and co-create value. This integrated business design focuses on the technical implementation of products, emphasizes service design and delivery to meet user needs and enhance user experience. During this transformation, the design protagonists in engineering have evolved into a composite system composed of engineering designers and highly intelligent artificial intelligence algorithms and robots. Engineering designers continue to undertake technical, creative, and cultural work. While artificial intelligence reduces the technical barriers to participation in engineering design, allowing stakeholders in engineering projects to participate more in the conceptual generation of engineering design.

Firstly, engineering design objects in the digital age exhibit significant characteristics of multi-disciplinarity, complexity, and diversity. Engineering designers are beginning to possess interdisciplinary knowledge systems to solve nonlinear engineering design problems. Engineering design now not only addresses tangible issues such as technology, structures, and aesthetics but also tackles intangible aspects such as the interaction between engineering objects and social systems, human experiences, interactions, values, and more. The service design is increasingly involved in the entire process of engineering, helping engineering designers better understand user needs, preferences, and behavioral habits to design products and services that are more aligned with user expectations. Engineering designers are beginning to focus on user-centered design, gaining deep insights into user needs, expectations, and challenges, tailoring solutions that better meet practical requirements for users.

Secondly, in engineering in the digital age, service design also involves optimizing interaction processes, interface design, information architecture, and more for products or services. By designing intuitive, concise, and user-friendly interfaces, users can complete tasks more quickly, reduce cognitive burdens, and enhance the fluidity and efficiency of their experiences. Personalized design and intelligent recommendation systems can provide users with more personalized service experiences based on their preferences and behavioral habits, enhancing user engagement and satisfaction.

5 CONSTRUCTION OF A ENGINEERING THINKING MODEL LED BY SERVICE DESIGN

This chapter mainly constructs an engineering thinking model led by service design from the dimensions of basic functions, cultural experience, and social value, in order to understand and even solve the intangible aspects of engineering such as culture and value.

5.1 Basic Functionality Dimension of the Thinking Model

Today, in rapidly evolving technological and increasingly complex social environments, the field of engineering faces unprecedented challenges that often exceed the scope of solutions provided by a single discipline or technology. Service design offers a powerful tool for integrating knowledge and optimizing engineering practices across different fields.

Firstly, the core of the engineering thinking model led by service design lies in promoting interdisciplinary integration. When faced with complex engineering problems, traditional single-discipline approaches often struggle to provide comprehensive solutions. The engineering thinking model led by service design encourages collaboration among experts from different fields, integrating specialized knowledge from various disciplines, enhancing the efficiency and effectiveness of problem-solving, coordinating the needs and constraints of different parties, and achieving more balanced and comprehensive engineering solutions.

Secondly, the engineering thinking model led by service design emphasizes the construction of dynamic technology clusters. In a rapidly changing technological environment, static technological thinking is no longer sufficient for the needs of the engineering field. Service design advocates for design-centered approaches, abandoning singular technological solutions, constructing interactive and highly integrated dynamic technology clusters to supplement the limitations of single technologies, support continuous technological updates and innovations, encourage the development of new technologies, and fundamentally improve engineering issues from the source to achieve sustainability.

Thirdly, the engineering thinking model led by service design can fully understand and address the complexity and uncertainty of engineering problems in social systems. Contemporary engineering problems within social systems often involve nonlinear, complex, dynamic interactions among multiple factors. The proposed thinking model can swiftly respond to the anti-solution problems in engineering

systems, address new demands arising from changing contexts, and significantly enhance the capacity to solve complex social problems in engineering.

5.2 Cultural Experience Dimension of the Thinking Model

The onset of the Industrial Revolution brought about significant technological advancements and economic prosperity to society, empowering further transformations of the natural environment and the creation of artificial worlds by humans. This greatly altered human survival and lifestyle but also led to a distancing in social relationships between individuals, between humans and nature, and between humans and society. The cultural experience dimension responds to the exploration of cultural experiences in engineering. Service design not only focuses on technological progress and economic prosperity but also strives to establish connections between humans and nature, society, exploring and responding to human aspects in engineering design, constructing a more harmonious and sustainable artificial world.

Firstly, the engineering thinking model led by service design can improve traditional thinking centered solely on technology or products, shifting towards a user-centered approach, respecting individual differences, returning to care for human nature, and responding to societal needs. Engineering projects are not limited to a technical perspective but integrate more humanistic care and social responsibility into engineering design. Through the proposed thinking model, engineers can better understand user needs, creating solutions that not only meet functional requirements but also enhance the quality of life for users.

Secondly, in constructing interactions between humans and society, nature, engineering design should focus on the combination of technology and life, considering the harmonious coexistence of design with the environment, life, and civilization. Engineers, in the design process, can consider the impact of engineering on the natural environment, pursue long-term ecological development, integrate sustainable development principles into design, and achieve harmonious coexistence between humans and nature, technology, and ecology.

Thirdly, in imbuing artificial worlds with meaning and value, the purpose of service design is to enhance human well-being. Engineers should contemplate the impact of engineering on society and culture, as well as how it satisfies people's aspirations for a better life. The goal of service design is to create a living environment that is both high-tech and filled with humanistic care, embodying integrity, natural human qualities, and visions of urban life, providing users with cultural experiences that align with local cultural backgrounds.

In summary, at the cultural experience dimension, the engineering thinking model led by service design requires engineers to consider not only the performance and efficiency of technology in the design process but also focus on human needs, social responsibilities, and environmental sustainability. Through service design, engineering designers can construct a more harmonious, sustainable artificial world, achieving unity between humans and nature, design and environment, design and life, design and civilization, technology and life.

5.3 Social Value Dimension of the Thinking Model

The engineering thinking model led by service design aims to create valuable user experiences and humanistic values, transforming engineering projects from singular technological solutions to comprehensive social and cultural phenomena, thereby realizing the social value of engineering.

Firstly, the service design-led engineering thinking model understands the localized needs and real constraints nurtured by different regional cultures, emphasizing the integration of engineering projects with local cultures and respecting cultural diversity. Service design can connect stakeholders from different cultural backgrounds, ensuring that engineering projects meet the needs of local communities, promoting overall harmony and development in society.

Secondly, in terms of the experience and humanistic value of engineering projects, the engineering thinking model led by service design transcends a purely technological perspective, focusing on the intangible values constructed by engineering projects. It encourages engineers to create interactive interfaces between humans and artificial environments, natural environments, constructing harmonious relationships between humans and society, humans and nature. By deeply understanding user needs and social values, the proposed thinking model takes a holistic approach from the perspective of the social system, assuming the responsibility of safeguarding the future development of society.

Thirdly, the engineering thinking model led by service design advocates a high sense of responsibility towards society, improving design purposes, returning to social morals and ethical norms, using the power of engineering design to balance the multiple interests in societal contexts, driving social reform and long-term development. It actively promotes engineering design for marginalized groups, addressing the unique challenges faced by these groups under existing designs, pushing society towards a more just, equal, and inclusive direction. It can provide a forward-looking perspective, pursuing a long-term and holistic order of human development, using engineering design to strive for a high-quality state of unified material and spiritual civilization. Basic Framework of the engineering thinking model led by service design as can be seen in figure2.

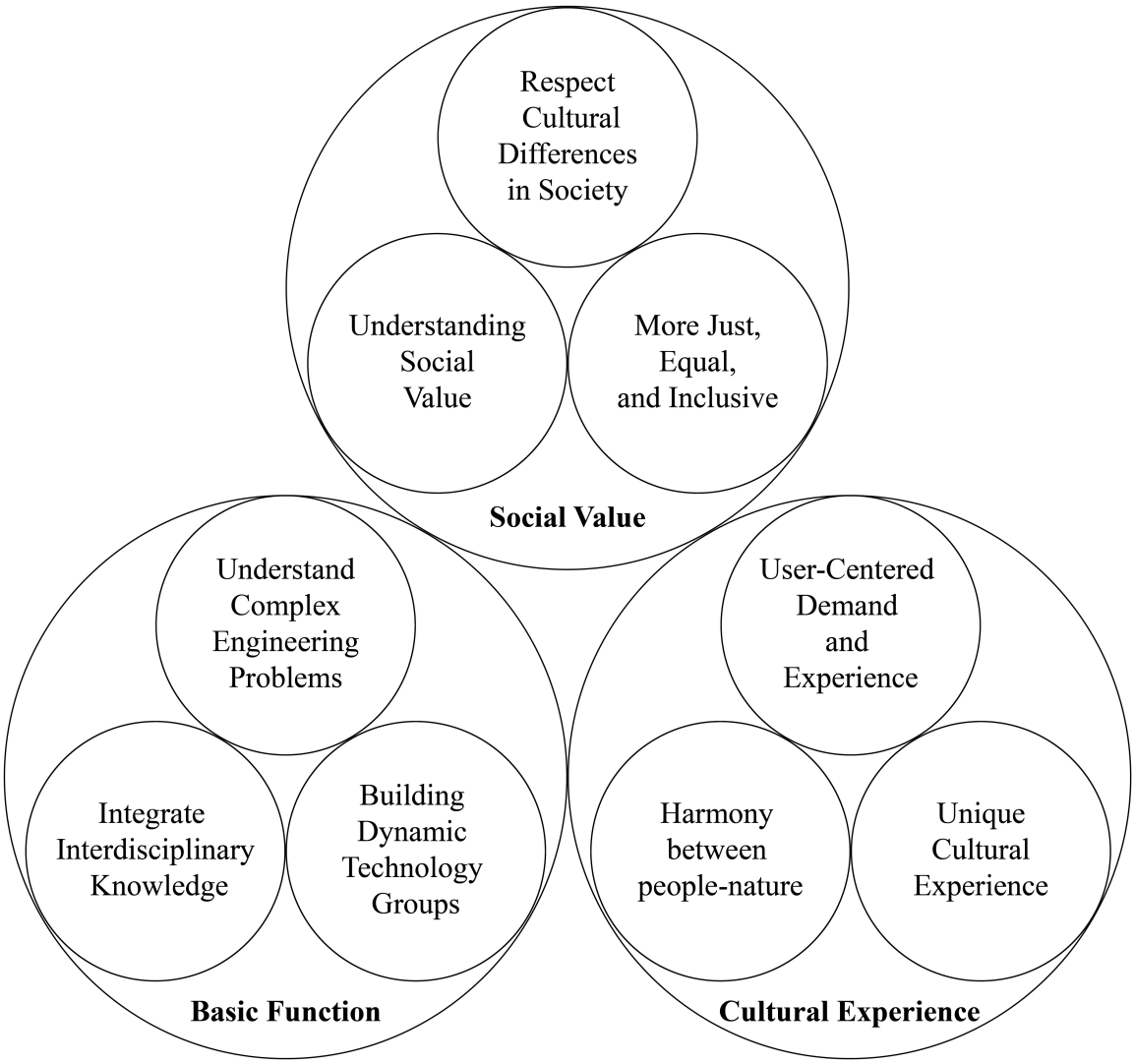

Figure 2. Basic Framework of the engineering thinking model led by service design

5.4 Interaction mechanism with existing thinking models

Generally speaking, existing engineering activities can be roughly divided into three stages: design planning, implementation construction, and operation maintenance. Design planning is the first stage of engineering activities, involving the conception and imagination of the "artefact" and its construction process, expressed through drawings, models, and schemes to represent the initial concept of the engineering. Implementation construction is the second stage of engineering activities, involving the application of various technical means and the use of natural materials to build the process of converting the engineering concept scheme into a specific project, which requires handling the relationships between people and people, and people and the environment. Operation maintenance is the third stage of engineering, involving the operation of engineering projects in specific social contexts, responding to specific engineering phenomena in social environments. It can be seen that in the functional rationality

engineering thinking model, engineering design is generally located in the first stage of the engineering activity process, providing conceptual design for the engineering. Meanwhile, each step of the engineering design needs to address the intangible user experience issues, but there is no relationship between the steps, so it cannot well intervene in the discussion of the intangible level. The phenomena of engineering design addressed by the functional rationality engineering thinking models and the engineering thinking model led by service design are shown in table1.

Table 1. The phenomena of engineering design addressed by the functional rationality engineering thinking models and the engineering thinking model led by service design

Number	Functional Rationality Engineering Thinking Models	Engineering Thinking Model Led By Service Design
1	Materials	Culture
2	Form	Emotion
3	Structure	Experience
4	Function	Meaning
5	Technology	Aesthetics

The engineering design thinking model proposed in this paper can be divided into three levels: basic function, cultural experience, and social value, each playing a role in the various stages of the traditional thinking model, complementing the existing thinking model to jointly address the service design issues of engineering design.

Firstly, in the design planning stage of the traditional engineering design thinking model, the thinking model proposed in this study precedes the understanding of the complexity and uncertainty in the social system, which helps to design engineering projects that can adapt to changes in social contexts and meet challenges, handling the relationships between people and people, and people and the environment in a more reasonable way. Meanwhile, the thinking model proposed in this paper encourages the construction of dynamic technology clusters, providing technology for the functional updates of engineering projects during operation. Secondly, in the implementation operation stage of the traditional engineering design thinking model, the thinking model proposed in this study can build cross-disciplinary teams, providing a platform for knowledge sharing among stakeholders in the engineering project, helping the relevant parties understand the entire process of the engineering and each other's work, and balancing the interests of various parties in the social context. Thirdly, in the maintenance stage of the traditional engineering design thinking model, thanks to the construction of dynamic technology clusters, the maintenance stage of the thinking model proposed in this study can promptly respond to new demands posed by social contexts to engineering projects, adding new functions to the projects or maintaining their usability, thus meeting the requirements of different social contexts for engineering projects and enhancing the user experience. The Interaction mechanism with existing thinking models is shown in table2.

Table 2. The Interaction mechanism with existing thinking models

Number	The Process of Traditional Engineering Project	The interaction Mechanism of the Thinking Model
1	Design	Understanding the complexity and uncertainty in social systems
		Addressing relationships between people and between people and the environment
2	Construction	Building cross-disciplinary teams
		Providing a platform for knowledge sharing among stakeholders in engineering projects
3	Maintenance	Responding promptly to new demands placed on engineering projects by social contexts
		Adding new features to the project

6 CONCLUSION AND FUTURE WORK

This paper explores the importance of service design in engineering design, reviews the development trajectory of service design in engineering activities, and constructs a engineering thinking model led by service design based on the theoretical framework of Contemporary Chinese design theory. It provides new perspectives and methods for addressing experience, value, and other non-material attribute-related issues in the field of engineering design. It is important to emphasize that the engineering thinking model proposed in this paper aims to efficiently address non-material phenomena in engineering design, as the commonly used functional rational engineering thinking model is adept at solving material-related issues. When facing increasingly complex socio-technical system problems, both approaches have their strengths and can complement each other. Future work will focus on testing and this thinking model, refining its details, further driving innovation in the field of engineering design, and meeting the complex demands of modern society for engineering projects.

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