Using Schema Theory to Construct the Designer's Knowledge Framework

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Abstract. Design knowledge is often categorized as tacit knowledge, but it is not randomly scattered within the designer's mind. Schema is used to capture the designer's knowledge, representing the structure of knowledge. This study explores the formation and use of design knowledge among designers through in-depth interviews, analysis of precedent works, and design task testing, outlining the structure of design knowledge frameworks. The research reveals that design knowledge is stored in the form of conceptual schema at different levels. The classification of conceptual schema is closely intertwined with the design process and outcomes. The structural framework of conceptual schema plays a crucial role in the retrieval of design knowledge, with different types of conceptual schemas able to retrieve different knowledge.

Keywords: Schema Theory · Conceptual Schema · Knowledge Framework

1 Introduction

For a considerable period, the process of moving from design problems to solutions has been referred to as a creative leap, where the solution generation process is considered invisible. But it does not exist disorderly in the designer's mind. It has a certain framework that allows knowledge to be systematically accessed during the design process. What is the specific structure of this framework? Can it be explicitly represented? Design knowledge is influenced by the accumulation of experience. There is a significant difference in the knowledge and experience that design experts and novices can access and process [1]. Before growing into experts, designers need to study a large number of design precedents, storing them in the brain through scenarios and experiential memory [2]. The Schema theory originated from Kant's inquiry into "how knowledge is formed and develops," with Bartlett and Piaget analyzing how knowledge is generated and developed through the memory and organization of experiences and cognitive processes, respectively. Minsky systematically explained the structure of knowledge by proposing the theory of the frame, stating that schemata are the structural units representing knowledge [3]. In the field of design research, schema theory has been used to capture designers' knowledge [4], assess the level of design knowledge [5], and represent the internal structure and innovation of design prototypes [6, 7]. However, it has not been systematically used to analyze the inherited framework of design knowledge and how

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the reasoning rules design thinking. Conceptual schemas serve as indicators to measure a designer's level of knowledge. Designers express complex ideas through simple words (conceptual terms) and phrases, which is precisely the process of conceptual formation or schema development. For example, a designer may use "Belvedere" to express an idea. However, for the designer, the schema of "Belvedere" is not limited to a specific observation deck, but rather a type of architecture, a device of vertical spatial organization aimed at providing dramatic perspectives and assisting users of the building in creating a mental map of their surroundings [8]. As knowledge and experience accumulate, the content and information contained within this concept become richer. During 4–6 years of professional learning, designers acquire knowledge and experience stored in memory, forming a database [9]. When engaged in design practice, the contents of this database are retrieved, converging into a designer's design world. Conceptual schemas, as the basic units of design knowledge, exist in the designer's database and design world. How do they interact? Drawing on schema theory, this study presents three questions regarding the construction of a designer's knowledge framework:

- What is the internal structure of design knowledge?
- What knowledge contents do designers access during the design process?
- How is design knowledge identified, abstracted, and transformed during the design process?

2 Methods

2.1 Study Design

This study aims to understand the process of knowledge and experience accumulation among designers through their professional learning experiences and design practice. The research employed in-depth interviews, precedent analysis method [5], and task testing with 5 designers for data collection. The study consists of three parts: interviews on design knowledge, precedent analysis of works, and design task testing. Each session with the participants was controlled to last for 90 min. The entire interviews were recorded, and all data were analyzed using the qualitative research software NVivo11 for coding. The interview section consisted of 5 questions regarding the understanding of design knowledge, the process of learning design knowledge, participation in design practice projects, experiences with precedent learning, among others. The precedent analysis section displayed a total of 10 visual renderings of design works[1]. Most of the selected examples were from Fortune Magazine's 2019 selection of The 100 Best Designed Products, representing famous examples of designers from the 20th to the 21st century. These examples were chosen to represent different aspects such as form, style, functionality, typology, and usage. The 5 designers were presented with images of design works and asked to verbally describe what they observed in the pictures. The process was recorded and transcribed using speech-to-text tools. For the design task testing, designers are presented with a photo of a bathroom and asked to design a chair for elderly people based on the scene information. The testing time is 40 min, during

[1] 1-Aeron chair, 2-iPhone, 3-Porsche 911, 4-OXO Good Grips Peeler, 5-Eames Fiberglass Armchair, 6-Model S Sedan, 7-Nokia 3210, 8-Apple Watch, 9-Poäng, 10-Box Chair.

which designers verbally articulate their thoughts on the design process. Data collection is conducted through protocol analysis.

2.2 Participants

Designers were recruited from design companies and design schools in Shanghai through purposeful sampling. Further selection was carried out using snowball sampling. The recruitment criteria for participants included: undergraduate industrial design major and practical design project experience. Initially, 11 designers were recruited, and then 5 designers were randomly selected from them.

2.3 Tools and Materials

Recording pen, interview script, portfolio of precedent works, task testing questions.

2.4 Analysis

The collected verbal reports are projections of the externalization and internal knowledge structure of designers, reflecting the objective content of design knowledge they possess. Research data were analyzed using the traditional content analysis method to create a main code book: Two doctoral students majoring in design from Tongji University were invited to review the consistency of data collection, which helped in a comprehensive understanding of the viewpoints presented in each interview.

2.5 Ethical Review

The research design, data collection tools, and consent forms were approved by the Research Ethics Committee of Tongji University. Participants were informed about the purpose and nature of the study, and informed consent was obtained before each survey, with participants signing informed consent forms. To ensure confidentiality, numerical codes (D1, D2, D3, D4, D5) were used instead of names for the five participants in the research data, and any data related to personal information was deleted.

3 Results

This study conducted in-depth interviews, precedent work analysis, and design task tests with five designers. The demographic information of the designers is shown in Table 1. The analysis results will be discussed in the following sections.

Table 1. Participant Demographics

Designer	Gender	education	work experience
Designer 1	Female	postgraduate	2years
Designer 2	Male	postgraduate	15years
Designer 3	Female	postgraduate	8years
Designer 4	Male	postgraduate	13years
Designer 5	Male	postgraduate	3years

3.1 Learning and Accumulation of Design Knowledge

Designer Professional Learning Process: Internalization and Integration. Designers study basic general education courses in the first two years of their undergraduate studies, and begin to engage in specialized courses such as comprehensive design exercises in the third year. In the graduate stage, they study subjects like psychology and market analysis, often mentioning design methods. Active learning among designers mostly occurs during the graduate stage, involving areas such as marketing, quantitative analysis, and service design.

Designers study foundational general education courses in the first two years of their undergraduate studies, and start professional courses in the third year, such as comprehensive design exercises. In the graduate stage, they study psychology, market analysis, and frequently discuss design methods. Designers see foundational courses as partial components of design knowledge that become internalized. They generally consider the most important course to be comprehensive design training, typically determined by teachers, with themes such as Bluetooth speakers, MP3 players, aiming to produce works through a complete design process. As the number of comprehensive design projects increases, designers begin to focus on design scenarios and issues. Terms commonly mentioned by designers in in-depth interviews are problem awareness, design process, and user needs. In the graduate stage, designers experience an increase in both the depth and breadth of design knowledge. When addressing challenges or situations lacking smoothness or rationality, designers start focusing on design scenarios and issues. After starting work, designers express that their core skills involve rapidly acquiring information and articulating problems quickly. Design knowledge is integrated into the design process and dispersed throughout every aspect.

Collection and Study of Design Precedents. Designers actively collect design precedents during their undergraduate and graduate studies to enrich their design knowledge. In their undergraduate years, they gather cases related to their personal interests, such as hand-drawn works (D1, D4), automobiles (D1, D4), furniture (D5, D3), and electronic products (D2). During their graduate studies, their focus shifts to cases and materials relevant to the design topics, such as interaction methods (D1), community innovation (D5), healthcare (D1), and elderly-friendly design (D1, D5). Designers collect these cases to understand the latest and best design works, either borrowing from or imitating their appearance and style, or analyzing their creative ideas and concepts. However, as they

accumulate work experience, designers begin to reduce their collection of cases and concentrate on exploring cutting-edge technologies, new consumer trends, and social innovations in the design field. They integrate this wealth of design knowledge into their design process to enhance their design proficiency.

3.2 Design Precedent Works Analysis

Analysis Framework for Design Precedent Works. Designers' analysis of the works demonstrates a consistent pattern, as they use professional terminology to categorize the works, and then provide detailed evaluations based on dimensions such as appearance, structure, form, material, function, usage scenarios, ergonomics, experience, and comfort.

Taking the four chair works as an example, designers typically refer to them as "ergonomic chair, recliner, office chair, folding chair," and evaluate them based on dimensions such as form, function, comfort, material, and ergonomics. Their evaluations highlight specific attributes of each design, such as using adjectives like "foldable, portable" for the Box Chair, "ergonomics, functionality, comfort" for the Aeron chair, "fashionable, structured, integral design" for the Eames Fiberglass Armchair, and "comfort, experiential sensation" for the Poäng chair.

This comprehensive analytical approach is particularly evident in evaluating the Box Chair, where designers analyzed it across 9 dimensions: form, function, structure, comfort, material, usage experience, user, manufacturing process, and production transport. Each dimension had further details, such as "hole design" under form, and "foldable > detachable > disassembly process > backrest storage" under function.

3.3 Different Concept Schema Influence Knowledge Retrieval

Designers Use Similar Problem-Solving Steps. The problem-solving steps of designers in the task testing are generally similar and can be summarized as analyzing the question, hypothesizing the problem, defining the problem, seeking solutions, and finalizing the solution and details. After reading the design task's title, designers begin by observing the provided scene images of the bathroom, examining the environment of the entire toilet (D4, D5), and analyzing the behaviors that the elderly might engage in the bathroom (D3, D4). Designers recall experiences to analyze the potential role of the chair in the toilet (D1, D2, D3), the reasons behind using the chair (D3, D4), and analyze possible problematic situations, proposing concepts such as "safety, ease of use, fatigue relief", etc. Subsequently, designers verbally articulate the problems they aim to solve, for example, designer D4 states: "My chair should be usable as a walking aid. First, analyze the problems, one is slipping due to wetness. Second, it can assist in walking. Third, it can be unfolded into a seat or a toilet seat at any time (D4)". Based on the defined problems, they proceed to specific designs, with designers sketching while explaining the structure and usage scenarios of the design proposal, and finally supplementing the details of the design proposal. Designers roughly outline the specific form of the chair, with two designers naming their design results as "Walking Aid D4" and "Bathing Stool D5".

Knowledge Retrieval in Design Tasks. Designers use the same design steps to complete design tasks, which include analyzing the problem, defining the problem, generating concepts, refining concepts, and creating solutions. Semantic analysis reveals that designers draw on different knowledge content in different steps. During the problem analysis phase, designers analyze key words in the task such as "chair", "bathroom", "elderly", and extract contents such as "using the toilet, washing, grandparents, my home, problem-oriented, chair as a result", and so on. Designers observe and analyze the bathroom images, describing not only what they see such as "washing machine, toilet, sink, shower head, steps", but also mentioning "elderly living alone, nursing home, hospital, bending over." By recalling past experiences, designers supplement possible scenarios in the photos such as "my home's bathroom, mobility issues, storage, cleanliness, convenience of use, habits, mobility space, narrow space, alarms, temperature control, faucet", etc., to help enrich the scene for designers.

The most mentioned words during the problem definition and concept generation phase are "slipping, sitting, lightweight, safe and stable, portable, movable, rest, toilet use, fatigue relief, alarm, support, walking aid, walker, toilet seat", etc. In the phase of refining the solution details, words such as "form, shape, assembly, material, disassembly, size, brakes, hooks, cane, armrest, lightweight, carbon fiber, aluminum alloy, chair back curvature, drainage,", etc., are mentioned. For the design outcome "chair", designers also use various expressions during the design process instead of just "chair", referring to it as "stool, bath aid, walking aid, cane, folding chair, massage chair, assistive device", etc.

In the data, terms such as "elderly living alone", "elderly in welfare homes", "normal elderly", "healthy elderly", "elderly with mobility issues", etc., represent different categories within the elderly population. The bathroom, as a setting, activates behaviors and facilities, for example, "washing clothes in the bathroom, well-equipped bathroom, squatting toilets, old-fashioned bathrooms", etc. Designers have accumulated concept schema about different groups of people and situations during their learning and cognitive processes, which are activated by semantic or visual stimuli. The design problems also have schema structures. When the task is focused on "a chair for bathing (D5)", details such as "cannot stand for too long", "temperature adjustment", "adjusting the position of the faucet", "having a showerhead on the chair", etc., are brought up by designers in their descriptions. The design outcomes also help in accessing knowledge. In the specific design task of "chair" in the test, designers accessed information related to chairs such as "seating, stool, folding chair, massage chair", etc., to describe the design scenario or express design intentions. Other items related to bathrooms and elderly use, such as "toilet seats, canes, bath aids, age-friendly equipment", etc., were also accessed during the thought process of the designers.

4 Discussion

4.1 Framework Structure of Design Knowledge Based

Designers' knowledge exists within a hierarchical framework, with conceptual definitions at the top level, specific categories in the middle, different dimensions expressing these concepts at the third level, and specific details at the bottom. This is akin to Minsky's schema structure, where concepts gradually develop into complete schema during the process of knowledge accumulation. The description of the design task "chair" overlaps with the analysis of design precedents because they are both part of the conceptual schema of a chair.

4.2 Experienced Designers Possess More Advanced Conceptual Schema

The learning experiences of designers show a transition from initially borrowing design details to later generalizing design principles and understanding future trends. This signifies the progression of conceptual schema to advanced stages. In the process of analyzing precedents, designers categorize cases by factors such as usage scenarios, structure, function, material, and behavior. Experienced designers have more diverse and innovative dimensions in their schema frameworks, including more detailed end details.

4.3 Influence of Design Learning Process on Conceptual Schema

Researchers have expressed concerns about excessive focus on design outcomes because it can lead to the formation of conceptual schemas based on design results. In this study's design task testing, it was found that designers almost uniformly utilized the same approach to solving design problems, namely the four steps starting from the problem. In these steps, there are repeated elements in the issues considered by designers and the knowledge they draw upon. From the design outcomes, it can be observed how designers utilize past design results and materials to formulate the final solution. This may remind us that design problem schema and design result schema could also be vital components of designers' knowledge content, exerting significant influence on the design process.

4.4 Influence of Design Knowledge Framework on Innovation

Gero proposed the FBS model in design knowledge research, illustrating the relationship between knowledge frameworks and problem solving [6]. Does having a rich conceptual schema for a certain concept mean we can solve all related problems? In this study, we analyzed designers' knowledge retrieval, where different stimuli evoke different knowledge content. Similar conceptual schemas and knowledge frameworks might impact how we retrieve and gather knowledge. Innovations in conceptual schema frameworks could be the core logic behind design innovation.

5 Conclusions

This study explored the structuring of design knowledge, focusing on the core issue of the framework in which design knowledge exists. It analyzed how design knowledge is constructed, its composition, and how it operates in design reasoning. Utilizing schema theory helped capture designers' design knowledge and elucidate its development and transformation during the design process. Due to the limited number of participants, there may be errors in the analysis dimensions of the design knowledge framework, which will be addressed in future research by increasing the sample size to ensure the accuracy of the study.

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