Understanding the Dynamic Nature of Design Knowledge

- A preliminary study on how knowledge is structured in comprehensive-studio based conceptual design

Jin Ma*, Xiangyang Xin, Sharon Poggenpohl

** School of Design, The Hong Kong Polytechnic University*
Hong Kong, China, ma.jin@polyu.edu.hk

Abstract: The understanding of Design knowledge remains fuzzy and largely implicit. Many theoretical investigations into this area propose diverse categorizations and models, either contextualized or formal, to understand design activities. Unfortunately, design knowledge exhibits various dichotomies whose boundaries can hardly be explicitly delimited due to its inherent ‚problematic' characteristics: the tacit and dynamic facets in contrast to the explicit and static ones. The premises and criteria behind these categorizations and models are not derived from the same or an equivalent basis, hence they are untransferable. Literature review on design knowledge reveals some fundamental tensions and challenges to design knowledge's dichotomies in respect of its dynamic nature.

The tacit and dynamic facets of design knowledge are intensively embodied in conceptual design (the early stage of design). The present study adopts a bottom-up approach using Grounded Theory methodology rather than theoretical investigations to look into design knowledge involved in conceptual design. Twenty-four experienced design educators from ten design programmes in mainland China were interviewed and a BA comprehensive industrial design studio was observed at Tongji University. By looking into substantive design activities and conceptualizing theoretical relations between the emergent actual categories through constant comparisons, a preliminary knowledge categorization framework is proposed.

This framework with different levels of abstraction for the early stage of comprehensive studio-based industrial design is characterized with the intermediate level of conceptual knowledge that features generativity and cumulativeness. As the key category, design prototype is conceptual knowledge constructions that embody these features based on the way in which they integrate knowledge, including higher level of principles, methodologies and lower level factual phenomena, into a unified nonhierarchical network. Being elicited from design practices, the emerging prototype framework and growing trajectories render design knowledge's dynamic nature, which sheds some light of the further study on knowledge structuring patterns in conceptual design.

Key words: Design Knowledge, Prototype, Knowledge Structuring, Conceptual Design, Grounded Theory.

1. Introduction

The understanding of design knowledge remains fuzzy. This may be particularly the case as using pre-determined knowledge categorization frameworks to examine design practices follows dichotomized coding schemata that is disconnected from practice. However, reflection upon these knowledge categorizations is largely overlooked. The dichotomies, which impede improvement of understanding of design knowledge's dynamic nature, tend to be stressed rather than bridged in these theoretical investigations. This paper investigates conceptual design (the early stage of design) practices to propose a preliminary design knowledge categorization framework using Grounded Theory; and re-energize the emergent knowledge categories by putting them back into the practicing landscape to allow their interrelations to emerge. The dynamic nature of design knowledge is addressed from a practice-based perspective.

2. Design Knowledge and the Challenges It Confronts

During its development into an independent profession, design has accumulated a considerable body of knowledge within practicing communities. It is knowledge in and about design as a coherent whole that is implicitly applied by practitioners, in the sense that it is expressed in "designers' transactions with materials, artifacts made, conditions under which they are made, and manner of making" [12]. Within design research's short history, researchers have tried to turn the previously implicit applied knowledge into explicit through all kinds of academic inquiries. Given the increasing body of explicitly encoded knowledge, design has begun to emerge as a discipline. However, once extracted from the practicing landscape, the fundamental issues concerning dimensions of design knowledge tend to be reduced to dichotomized categorizations, based on which further theoretical investigations into design practices are carried out. Polarized between dichotomies that have been developed based on different layers of epistemologies, these knowledge categorizations are untransferable and incommensurable. They can serve as neither complementary nor as extensions to each other, and largely fail to capture the nature of design knowledge characterized by the dynamic intermediate spectrum. As many researchers criticize recently [3], design research has been heavily tilted towards the theoretical end, studying de-contextualized actions and processes that end up unable to account for the "real world" practice.

2.1 Dichotomies and Theoretical Investigations

Dichotomies are deeply embedded in traditional theoretical investigations on design knowledge in terms of categorization framework and the underpinning paradigm. The paired poles such as tacit and explicit, subjective and objective, declarative and procedural, goals and strategies, etc, do reveal the vast territory of design knowledge, but they reveal little about how to map onto it in a coherent way. Nevertheless it is a very popular logic, if not dominant, in the existing literature to look into design practices from a knowledge perspective with pre-determined theoretical categorization frameworks [1,7,8]. Empirical studies are conducted to verify these frameworks developed from literature, making possible codified design practices. This approach rests upon positivist dichotomies that separate means from ends, research from practice, and knowing from doing [11,13]; they stress the gap between theory and practice. Scholars such as Narvaez have pointed out that "fragmentation of design process, such as rational and irrational aspects, and logical and creative aspects, impedes the understanding of holistic design thinking" [9]. It is fruitless to advance the dimensions of the knowledge

involved in practicing based on these cut-and-dried dichotomies. The predicament is, investigations into design knowledge itself lag behind the studies based on it.

2.2 Tensions Inherent to Design Knowledge

In contrast to the dominant positivist paradigm, Donald Schön emphasized the importance of reflection-in-action in his reflective practice paradigm, which implies the value of revisiting knowledge identification that is grounded on situated design practices. Schön [12] shared his insights into design knowledge by articulating four pairs of tensions inherent to this domain: tacit and explicit knowledge, uniqueness and generality, generativity and cumulativeness, and plurality and commonality. Among them, generativity and cumulativeness are the most outstanding features that existing literature on design knowledge can barely account for, as they feature the dynamic nature of design knowledge.

2.3 Lack of Consistent Agreement on Key Terms

The characteristics of dynamic facets of design knowledge are intensively embodied in conceptual design, which is full of complexity, uncertainty, uniqueness, and value conflict [11]. Without reasonable frameworks to accommodate the dynamic nature of design knowledge, hiding knowledge with "bad words", as Frascara [4] seriously criticizes, is almost an inevitable consequence. Terms like design concept, intuition, research, creativity, and so on are intuitively used and loosely referred to by practitioners. Even design research lacks "a reasonable infrastructure including agreement on key terms" [10]. These "bad words" become the routine mysterious shelters that bypass the necessary knowledge regarding their subject matters and evolving processes. To look into core knowledge accumulated around these key terms requires consistent frameworks to position the terms.

2.4 Emergent Bottom-up Approaches

While design practices develop with their subject scope expanding and principles and methods advancing, the knowledge in design evolves too, and deserves a continuous examination. It is also an opportunity to enhance design theories' relevance with practices. Solely relying on pre-determined knowledge frameworks to examine the ever evolving design practices is paradoxical. To tackle this issue there is emerging interest in bottom-up approaches, e.g., Poggenpohl's rigorous study of design key terms definition [10] used groups of designers to define terms. The coding scheme emerges and evolves through rounds of analysis rather than being pre-determined.

3. Grounded Theory Methodology in Design Knowledge Identification and Preliminary Findings

Grounded Theory (GT) is an analytical inductive methodology balancing induction and deduction through the constant comparison procedures. It supports bottom-up conceptualization from substantive data. To look into knowledge frameworks in studio-based conceptual design practices, twenty-four experienced design teachers from ten Chinese BA industrial design programmes were interviewed with semi-structured questions. Teachers were encouraged to give examples regarding students' conceptual design practices in different types of projects. And they were asked to describe some particular student's designs and processes, and the situations in which they use references in design reviews with their students, etc. The study scope narrowed down to comprehensive

studio-based projects to study design knowledge on a more integrative practicing landscape rather than particular skill-oriented training in foundation projects. Then a BA graduation project tutorial was observed in the industrial design programme of Tongji University. All the interviews and observations were tape-recorded and transcribed immediately. The interview questions and observation focus underwent temporal modifications directed by the preceding rounds of constant comparative data analysis and theoretical sampling.

3.1 Constant Comparison Procedures of Grounded Theory

The emergent knowledge categories are constantly tested, reconstructed, eliminated if unfit in the ongoing analysis of new data, while new categories emerge in this process. Meanwhile, hypothetical relations between these substantive categories are generated and recorded in theoretical memos focused on integration of the growing knowledge categories. These emergent theoretical categories hypothetically direct further sampling of data collection and undergo comparisons with the emerging theoretical relations in the following analysis in return. Whether they work is tested in coding new substantive data, and recording by new memos. This is a back-and-forth process of GT's constant comparison methods. Knowledge framework will ultimately be integrated, as Glaser claimed in his book Theoretical Sensitivity that conceptualized theoretical relations to "weave the fractured story back together again" [5].

3.2 Initial Categories about Knowledge in Conceptual Design

Accompanied with the twenty four interviews and a studio-based design tutorial observation unfolding, the first several rounds of GT substantive coding ended up a big trunk of category list with 93 categories as of 5 Jan 2009, covering everything but giving little insights into integration. They clustered around some categories like teacher goals, project development, student performance, etc. Not until the focus on "design concept" as a linkage that reflects design knowledge emerged, did a concise but relevant category list come into being (Figure.1). Design prototype emerges as the key category among others through GT's constant comparison procedures. In view of this ongoing GT procedure, the list is open to further modification.

Knowledge as subject of actions		**Actions towards knowledge**		**Knowledge's roles in conceptual design**	**Frame of knowledge**	
Theoretical knowledge	*principles*	Delimiting	*merging*	Boundary conditions	Levels of abstraction	*macro / micro views*
	methods		*trimming*	Criteria		
	theories	Emphasizing	*transcending*	Driving forces		*abstracting / concretizing*
Conceptual knowledge	*concepts*		*contextualizing*	Consequences		
	prototypes	Balancing	*differentiating*	Context		*theoretical / conceptual / substantive*
Substantive knowledge	*factual phenomena*		*continuity maintaining*			
	domain specific knowledge (DSK)	View shifting	*macro view to micro view*			
			micro view to macro view			

Figure.1 Emergent elements of Knowledge in Conceptual Design (as of 18/04/09)

3.3 Prototypes as Conceptual Design knowledge

In the preliminary summary of emergent elements of knowledge in conceptual Design (Figure.1), three levels of knowledge in the early stage of comprehensive studio-based design practice are identified. At the abstract level is

the theoretical knowledge: principles, theories, and methods. The factual phenomena and diverse domain specific knowledge (DSK) is substantive knowledge located at the contextualized level. At the intermediate level is the conceptual knowledge characterized by design prototypes and related concepts. Design prototype has earned the key category position due to the way in which it integrates different levels of knowledge into a unified nonhierarchical network. It intensively embodies the generative and cumulative nature of design knowledge. Differentiated from Schön's definition of "types", prototypes, the alternative term in this study, are intermediate conceptual design knowledge in the first place, and then the "holding environments for knowledge" [12] as provisional propositions that "can generate sequences of moves and guide designing". Studying prototypes as outputs as well as the trajectory of conceptual design provides us with an opportunity to understand the dynamic nature of design knowledge.

3.3.1 Prototype and Concept

Concept is the basic element of intermediate conceptual knowledge. In this study, a concept is the common property found in a collection of indicators. A concept is free of its indicators' contexts, more abstract than, and thus independent of its indicators, e.g., the concept of utility is abstracted from many cases about the purposes users expect from using products. Remote communication is one of the utilities of a mobile phone, and wheeled luggage is for storage and mobility, etc. However, with any substantive utility indicators added or eliminated, the concept of utility remains intact. Concepts can be compared in terms of abstraction level only when they have lineal relations. In this case utility is more abstract than storage and mobility.

Different from the lineal and hierarchical concept-indicator mode, a prototype models a set of subject matter concepts with certain structuring relation concepts. A prototype is contextualized with its concepts, some of which cluster as sub-prototypes. When any sub-concept/prototype changes, the prototype changes too. In view of this feature, prototypes' levels of abstraction are incomparable. Width and depth of contextualization are more relevant indices to compare prototypes. The diagram below illustrates a prototype family (Figure.2). All the categories are generated from the interviews and an observation of a comprehensive design studio tutorial with user-centered approach. This prototype family is tentative and subject to modification through further data collection and analysis.

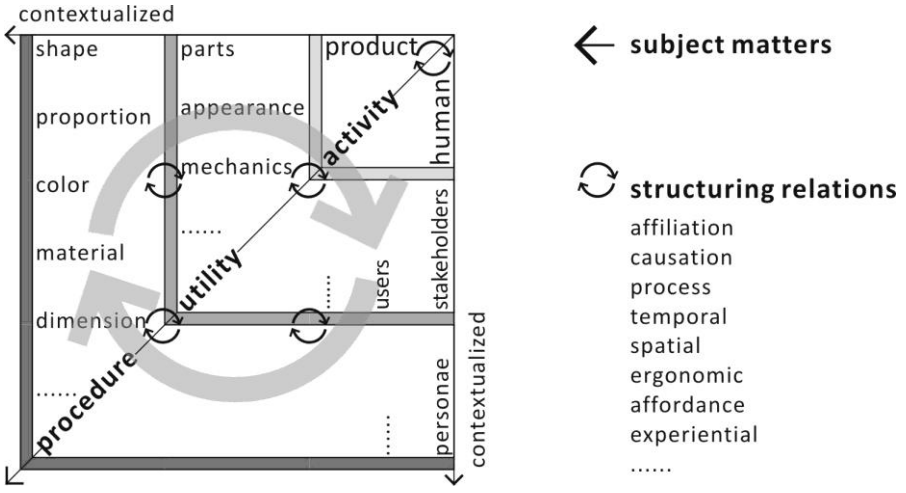

Figure.2 Emergent Prototype Family in User-centered Approach (as of 20 May 2009)

Prototypes are made up of two main categories: subject matters and structuring relations. Based on user-centered practice, the subject matters cover three domains: activities, products (subjects of design), and human beings. (1) Activity prototypes are elicited from factual phenomena from the very beginning, linking product and human prototypes with affiliation, causation or experiential relations; activities get contextualized when utility prototypes emerge. (2) Utilities drive products to become contextualized with product parts (handle, lid, etc.), appearance, mechanics, etc; and human beings contextualized as users and stakeholders. Processes, spatial, temporal, and affordance relations actively connect the sub-prototypes in product and human domains in the service of utility prototypes. (3) Procedural prototypes play similar roles to utilities, but in a more contextualized sense. The product's shape, proportion, color, material, dimension prototypes and diverse personae are focused to reciprocally delimit action sequences. Likewise they are combined with processes, temporal, spatial and ergonomic relations. As for the structuring relations that integrate equally or differently contextualized subject matters, they have at least two layers of functions: (1) indicating the status or assigning roles to subject matters in the prototype; (2) exerting operation rules upon them. Literally, a prototype is a network with depth and width. Without structuring relations, the subject matters are abstract concepts or linear and scattered concept clusters. Particularly, some relations lead to cumulative and generative prototypes.

Based on this understanding of prototype and concept, the ambiguous term "design concept" refers to the prototype network at a particular time point in the design process. A prototype may be featured with either its subject matter concepts or its structuring relational concepts, depending on the tentative role the prototype takes in the particular situation. This fact reveals the loose usage of "design concept". Sometimes a design concept refers to the whole network, no matter how fuzzy or contextualized it may be, and takes the form of a story. Meanwhile it is also used as the synonym of some particular sub-concepts in that network, illustrated with keywords.

3.3.2 Driving Forces Inherent to Prototypes

The width and depth of a prototype determines its power to generate or direct the generation of new prototypes. For example, a teacher illustrated an existing design example in her design review, referring to a book favored among the students: "*it's a tea bag designed by Naoto Fukusawa, the puppet-like one. A tea bag is meant to be like this (gesturing an up-and-down action of pulling the string in a tea cup). It's somehow turned into an action of manipulating a string puppet. I smile whenever I see this design (observation notes: SD080325TJ).*" All the tea bag parts (the bag, string, and handle) and corresponding procedure prototype bound in a unified whole facilitates the utility of tea drinking, which is a very basic affordance prototype. The string (product part) and the up-and-down procedural prototypes of this tea bag leads to the utility prototype of playing a string puppet that belongs to a previously irrelevant activity. This fluent flow illustrates an experiential prototype embedded in Fukusawa's tea bag. Compared with directional affordance and experiential prototypes, general utility prototypes such as "tea-drinking" give less insight in terms of what–to-do-next, because they have limited width and depth. Affordance and experiential prototypes are either vertically or horizontally contextualized, or both. Before they get saturated, they drive the growth of a prototype network, inviting subject matters beyond the current domains, and therefore enrich the final network's width and depth. In the case of Fukusawa's tea bag, the final affordance prototype is extended, as the utility prototypes are extended to tea-drinking and puppet-playing (Figure.3).

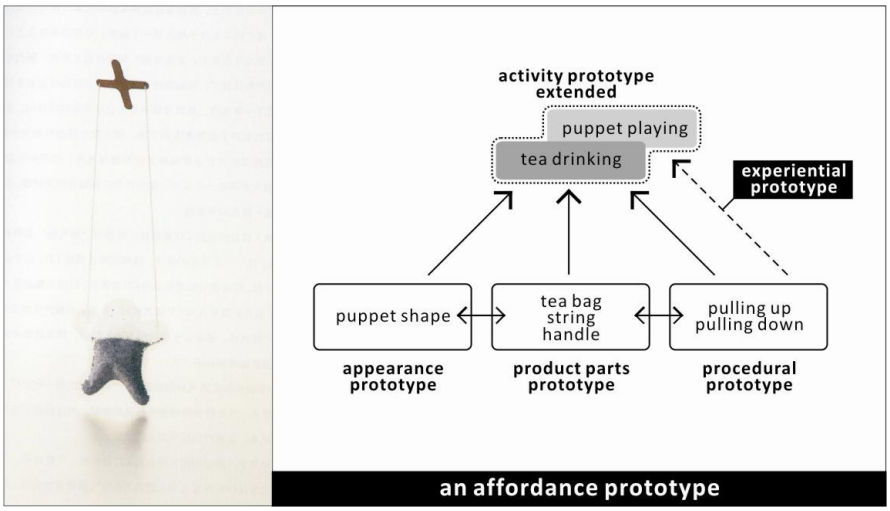

Figure.3 Affordance Prototype & Experiential Prototype (tea bag photo from *Designing Design* by Hara K. [6])

3.3.3 View Shifting in Prototype Structuring

Many teachers use the metaphor of shifting back and forth between macro and micro views to describe the conceptual process, and claim it is an efficient way to develop "concepts". Frequent view shifting movement has been identified in the empirical data. To address this issue from the prototype framework perspective, the case is when practitioners zoom from a macro view into a micro view, some focused concepts are driven contextually deep down as prototypes; when micro to macro prototypes are abstracted, concepts to be contextualized cross widely different domains. In view-shifting, prototypes as "generative abstractions" [12] have the transcending power to expand acquisition of substantive knowledge. Meanwhile some previously implicitly used prototype combinations reoccur so frequently that they become stabilized; they may be able to transcend the ephemeral and become bottom-up principles and methods. The theoretical knowledge acquisition grows as well. The intermediate network therefore combines the theoretical and substantive levels of knowledge.

4. An Example of Prototype Structuring Process in Conceptual Design

This is a three-month open-ended BA graduation project of industrial design, kicked off with two keywords: house-renting and furniture. This slice of data is taken from a one-on-one tutorial in week 4 (observation notes: SD080325TJ), when student Michael (descriptive name) was discussing his preliminary schemes with tutor Lena (descriptive name). Michael did a user research presentation before showing his concept sketches.

> He started with "*we've analyzed the relations between furniture and house-renting*", frequently drawing fuzzy activity and product prototypes based on his observations and interviews with the target users. E.g., "*the furniture provided by the landlords is worn-out and old fashioned"; "he put books inside the wardrobe, as well as clothes"; "the renters still have to buy some furniture. Not necessarily the whole set, but some particular pieces"; "if they do buy new furniture, how to fix it when delivered and how to take it apart when moving out are headaches.*"

Then he raised his scheme using a utility prototype: "*my concept is portable furniture*", and immediately began to contextualize it with appearance, procedural prototypes: "*put an individual piece into a box*"; "*the box would be about 700mm long*" and clarified the dimensional prototype was determined by the "moving out" activity as "*it should be accommodated in a taxi trunk*".

Finally he synthesized his schemes as: "*ultimately it would be like a travel luggage. You can pull it like this (showing the sketches)… Maybe it's a storage box. Each piece looks like a box. Several pieces can be stacked and pushed forward: bed, table, wardrobe, for instance. When the furniture pieces in the box taken out, the box is ready for storage. I guess the lid might be drawn in this way, and folding behind, then the three boxes can be nested into one another to make one storage box for miscellaneous."* Utility, appearance, product parts, procedure, mechanical prototypes were generated to develop the whole conceptual network as illustrated in Figure.4.

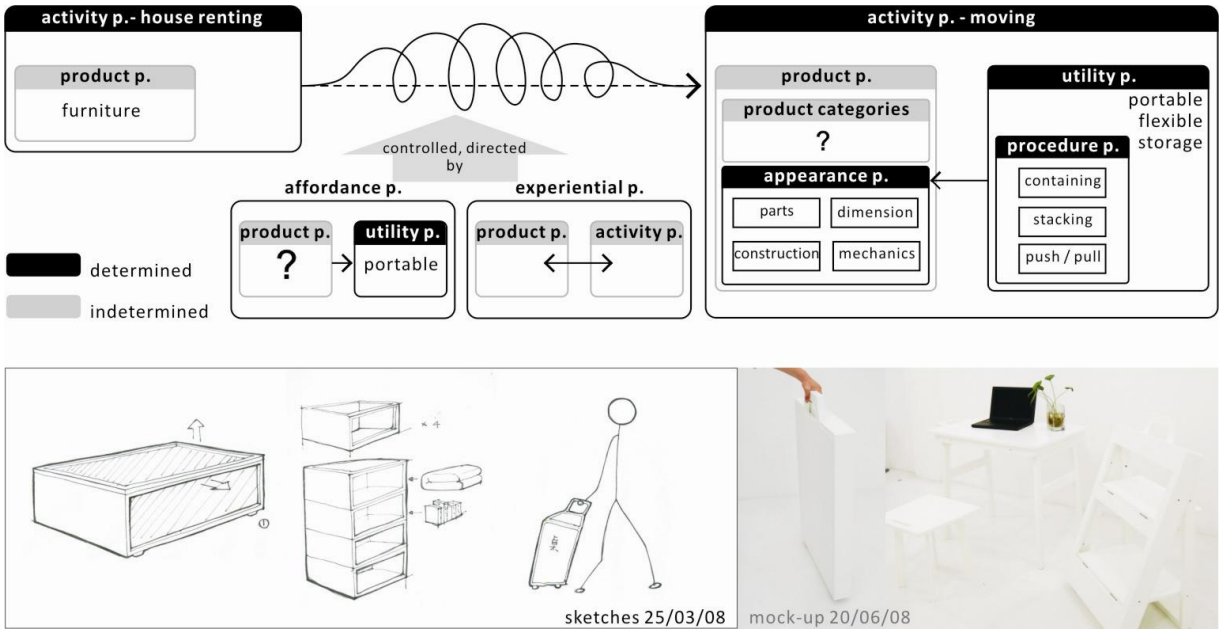

Figure.4 Portable Furniture Project

As tutor Lena commented, the idea of contextualizing furniture within the "moving" activity is "smart and constructive". New prototypes like "travel luggage" and "wheeled storage box" were invited by experiential relations. Affordance relations emerged, confirming portability as utility and expanding it to a combination with flexibility and storage. Simultaneously product related prototypes (parts, appearance, etc) were concretized as well. The originally undetermined and abstract prototypes were cumulatively determined and contextualized.

Conceptual design aims at obtaining holistic and consistent decisions to model the relevant factual attributes of design's subject matters. Both subject matters and their interrelations accumulate layer by layer. They emerge as scattered and incoherent clusters, and get modified and interwoven with newly elicited prototypes into a coherent whole. The provisionally determined prototypes act as criteria, rule, or condition demonstrations to generate new ones, which develop from the old ones in return; the process is dynamic. The undetermined network is

cumulatively transformed to a more determined one directed by certain prototypes. Conceptual design is therefore a parallel case of Dewey's inquiry pattern [2].

5. Summary Remarks and Implications to Further Study

As the first part of an ongoing project, this preliminary study has identified three levels of knowledge in conceptual design and proposed a prototype framework (combining subject matters with structuring relations) to look into the dynamic intermediate level. As a horizontally and vertically contextualized network grounded on the practicing landscape, the framework bypasses the routine and unconstructive dichotomies (including theory and practice), while it accommodates rather than stresses them. The integrative prototype framework sheds some light to the dynamic nature of design knowledge and accounts for its generativity and cumulativeness to a certain extent. Prototypes function as provisional propositions that "can generate sequences of moves and guide designing" with their inherent driving forces based on directional affordance and experiential relations. In addition, the subject matters and their interrelations accumulate layer by layer, and reciprocally determine and expand each other into a contextualized network. This framework emancipates the tensions of design knowledge's generative and cumulative characteristics that pre-determined dichotomized frameworks fail to explain. By virtue of the framework, some fluid terms such as design concept and conceptual design are re-constructed. It indicates that more "bad words", for example, "design language" can be understood and positioned upon this consistent base. A concise conceptual design glossary will be a byproduct of this framework. Besides, design episodes hinged on these terms such as early convergence have the opportunity to be revisited.

GT has proved to be a fruitful alternative approach to investigate design knowledge structuring. Nevertheless we understand that there is a thin line between forcing and allowing theoretical relations to emerge. For example, when the level of abstraction framework works well to identify the theoretical, conceptual and factual knowledge involved in conceptual design, it tended to be diffuse, including the intermediate prototypes and concepts. As a result, this forced theoretical framework caused trouble regarding identification of intermediate knowledge. Then we realized that this forced framework would lead to lineal and hierarchical concept trees, which do not work in practice. Finally it was suspended. Integration of subject concept with structuring relational concept as the contextualized prototype has emerged and earned its relevance through practical empirical data. The effective remedy to hold back preconceptions is to keep testing the categories in data and writing memos about the tentative interrelations.

Writing an article puts us in the comfortable position of reflecting on design knowledge, allowing us to conclude that further research is needed. Study on how knowledge is structured in comprehensive studio-based conceptual design calls for frameworks to re-energize the categorization of knowledge by introducing its situations, eliciting its evolving trajectories and identifying its contributions to design process. The categories of prototypes proposed in this preliminary study are generated based on limited data and within a substantive area. Given the diversity of design approaches and the expanding scope of the subject of design in Chinese education, more contextualized knowledge structuring patterns may emerge. Whether they are transferable to other design domains leads to further study.

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