Proceedings of the ASME 2019
International Design Engineering Technical Conferences
and Computers and Information in Engineering Conference
IDETC/CIE2019
August 18-21, 2019, Anaheim, CA, USA

DETC2019-98362

INVESTIGATING INFORMATION: A QUALITATIVE ANALYSIS OF EXPERT DESIGNERS' INFORMATION REPRESENTATION AND STRUCTURING BEHAVIORS

Nicole B. Damen
The School of Interdisciplinary Informatics
The University of Nebraska at Omaha,
Omaha, Nebraska, USA
Email: ndamen@unomaha.edu

Christine A. Toh
The School of Interdisciplinary Informatics
The University of Nebraska at Omaha
Omaha, Nebraska, USA
Email: ctoh@unomaha.edu

ABSTRACT

Information organization and utilization are integral to the design and development of creative ideas. However, navigating this often complex information space can be challenging, even for experienced designers. Therefore, deep analysis of how expert designers utilize and organize information is needed to provide qualitative insights into their information organization strategies. To address this, four professionals in the software design and development field were recruited for individual 3-hour design sessions. They were asked to generate ideas for a design challenge (reducing distraction-based pedestrian accidents) using information sheets specifically developed to contain different types of information, as identified by prior work. Results reveal individual differences in information approach and categorization, although these were motivated by similar underlying patterns of evaluating the relevance of information for its ability to inform the project constraints, resources or (user) requirements. Designer experience and use of design processes and knowledge transfer tools enhanced their ability to turn information into insights.

KEYWORDS

Information representation, early-phase ideation, design experts, knowledge, problem definition, design cognition

1. INTRODUCTION

Technological and recent information technology trends such as big data and cloud computing are lowering the barriers to innovation by commoditizing information. Despite these changes, successfully harnessing information to produce actionable design goals remains a challenge. This is because more information does not necessarily lead to better design outcomes. Indeed, too much information can lead to information overload [1]. This is especially true for less experienced designers who run the risk of encountering "design paralysis" when confronted with more information than they necessarily know what to do with [2]. As the potential information space has essentially become infinite, designers are limited by their bounded rationality and may struggle with systematically evaluating which sources of inspiration to attend to during the design decision making process.

In addition to the availability of information, certain information characteristics, dimensions, and forms have also been shown to play a vital role in the design process. For example, design teams have been shown to focus on the end goals of the project [3] and engage in abstract levels of information processing as a way to facilitate their solution development strategies [4]. The use of examples has also been found to be a staple activity for many designers and is often utilized throughout the design process for multiple reasons, such as evaluating essential and desirable features from similar solutions [5]. However, research also cautions against the use of examples, as they increase the chance of the designer becoming fixated. Fixation was originally defined as "a blind adherence to a set of ideas or concepts limiting the output of conceptual design" [7, p.3]. While design fixation reduces creativity, researchers have also expressed doubt at the perception that design fixation is always a bad thing, noting that fixation might be observed at one level whilst creativity is observed at another [7]. Designers must manage the tension between utilizing rich inspiration sources while carefully controlling the exploration of the solution space. As such, research that critically explores the influence of information during the design process can help the design discipline respond to this tension, and can contribute to our understanding of how to effectively support design activity. Therefore, this study addresses this gap through a detailed analysis of the behaviors of expert user-experience designers in the context of understanding, structuring, and responding to information early in the design process.

1.1 Design Cognition and Information Structuring

While empirical data on how design experts navigate the vast space of available information early on in the design process is sparse, theoretical models of creative cognition have explored the factors influencing design practice and developed models to represent the design process [8,9]. Research in this space has shown that design cognition relies on a combination of domain knowledge, or expertise [10], and effective application of required processes [11]. This can be done through the use of knowledge structures, which are thought to consist of knowledge that is schematic, associational or case-based. Schematic knowledge is semantic in nature, based on concepts and principles abstracted from past experiences (e.g. birds fly and have feathers), associational knowledge contains associated concepts (e.g. early morning is associated with bird song) while case-based knowledge contains contextual information to guide behavior in similar situations (e.g. goals, key actions, outcomes, contingencies, restrictions, and potential opportunities) [12]. These knowledge structures have been linked to the generation of creative ideas [13], although there does not appear to be one ideal knowledge structure for idea generation. Prompting a single knowledge structure was found to generate more high quality ideas, but prompting multiple knowledge structures was related to more high quality and more original ideas [12]. This indicates that designers may rely on multiple knowledge structures depending on their need. In addition, designers' ability to reorganize their own knowledge basis was found to be related to more innovative ideas [14], indicating a potential benefit of self-awareness and metacognition in building design expertise.

These knowledge structures are also influenced by expertise. Experts are known to be able to handle more information than novices [15], a finding often attributed to their ability to chunk information in their domain of expertise [16]. Additionally, the application of relevant processes also plays a role in successful problem solving in design. Although novices initially approach problems using a basic surface-level structure, when they were trained in relevant problem solving principles they were able to approach problems more similarly to experts. This provides support for a shift in people's knowledge base as these become richer with experience [17]. Many of such similar factors have been formalized into a process like the Design Thinking methodology [2] or through a set of design principles which may or may not be explicitly codified [18]. Information is a key aspect of these models of design processes and the building of these knowledge structures. The value that information brings to the design process depends on many factors, including the characteristics of the information itself. Knowledge on how these information characteristics interact with each other to influence the design process is critical, but understanding what these factors are is complicated due to the dispersed literature on this topic. Research is spread across various disciplines such as operational research [19], business [20], information science [21], engineering [22] and marketing [23]. To address this issue, prior work has begun the development of a typological framework for characterizing design information [24]. The following sections discusses the initial development of the Information Archetypes Framework.

1.2 Understanding Design Information through Dimensions and Archetypes

The previous sections highlight the need for a systematic investigation of the relationship between information types and the design process. One way to support this is by following a typological approach to building theory, as outlined by [25], and has been applied in other fields such as organizational science and social psychology (see [26–29]). According to this approach, a theoretical understanding of applied phenomena can be captured through the development of dimensions and archetypes. First, dimensions are developed in order to capture specific aspects of an entity. Then, more complex phenomena are understood as unique combinations of multiple dimensions that describe sets of ideal types, also known as Archetypes. A deeper understanding of the observed space is obtained through the process of developing these archetypes.

Closely following this approach, prior work has begun the development of the Information Archetypes Framework by classifying information used during design decision making in an open source context [24]. This work was focused on understanding the types of information used by designers based on subset of interview and focus group data from a larger field study conducted over a five year period. This resulted in the discovery of several information dimensions through a series of discussions, preliminary analysis of the transcribed interviews, reflective experiences gained during the field study, and review of related work. These information dimensions were then refined using a rigorous coding process conducted on the interview transcripts, following the principles of deductive content analysis [30]. The resulting findings were incorporated into a preliminary framework consisting of five main information dimensions with each two corresponded levels. The details of each dimension [24] can be found in Table 1.

TABLE 1. OVERVIEW OF THE FIVE MAIN INFORMATION DIMENSIONS AND THEIR SUBLEVELS [24]

Dimensions	Levels	Definitions
Source: Where information originates from	Internal	Within the individual, team, or organization
	External	Outside the individual, team, or organization
Abstraction: Level of detail in the information	Abstract	Vague, conceptual
	Concrete	Detailed, descriptive, relates to specific events
Generality: How generalizable information is across domains	Cross-Cutting	Can be widely generalized across various design domains
	Domain Specific	Is exclusive within one domain of design
Effectuation: Approach taken when presented a design problem	Effectual	Creating design with available resources in mind
	Causal	Creating design with an end goal in mind
Representation: How information is delivered to designers	Asynchronous	Communication not in person or real-time
	Synchronous	Communication in person or in real-time

This initial framework provides a basis to build theory around the use of information in the design process and enables researchers to empirically test the impact of specific types of information on design outcomes. As this is a preliminary framework, further empirical validation is necessary to advance its predictive and explanatory capabilities. This study uses this framework as a basis for investigating how designers use and structure information in the early phases of the design process. Detailed and systematic investigation into expert designers' strategies, reasoning, and methods for engaging with large volumes of relevant information early in the design process will provide insights into the cognitive processes employed to make sense of this complex space [31]. The next section presents the main goal of this research in response to this need.

1.3 Research Objectives

The previous sections highlight the role and importance of information on the creative outcomes of the design process. While it is clear that information can shape decision making, it is less clear how the characteristics of said information might impact designer behavior and cognition. Research on the information processing strategies of designers is needed to extend the existing body of work on the design process. Furthermore, research conducted with practicing designers will shed light on the complex processes employed in the field and add to our understanding of how experts have learned to engage with this information during design. Therefore, this work is guided by the following main research objective:

Understand the strategies used by expert designers to organize relevant design information during an early-phase design task.

Designers are known to draw upon various forms of information during a design task such as exemplars [5] and user requirements [32]. However, not all information is equally important to the design process. It is important to carefully examine the types of information being utilized during the design process to ensure that new design practices and approaches enhance, not undermine, the creative process. Therefore, investigating the ways in which designers organize and make sense of available design information will shed light on the ways in which the use of information influences the (early phase) design process. This study focuses on increasing understanding of both designers' reasoning process of developing organization strategies and the resulting scheme for organizing information to address the conceptual phases of a design task.

Specifically, this research goal will be addressed by analyzing 1) how designers visually organize relevant information prior to idea generation, 2) what designers' reasoning process for developing organizational strategies are and 3) how designers typically engage with and structure information in their everyday practice.

2. METHODOLOGY

An in-depth qualitative study was conducted with a total of 4 expert designers. These designers all practice design, carry between 3 to 8 years of experience, and were employed by small to medium software design and development companies in the U.S. midwestern metropolitan area (see Table 2 for relevant participant characteristics). All participants were identified through the authors' professional networks and through snowball sampling. Only designers who had obtained at least 3 years of software design experience (through educational training, certification, or job training) *and* currently engage in design activities as their primary function in their full-time jobs were recruited for this study. To reduce domain as a confounding factor, only software designers were included in this iteration of the study. The applicability of the Information Archetypes Framework in other domains is beyond the scope of this paper.

Despite the small sample size of participants in this study, *purposeful sampling* and deep analysis of expert behaviors in the context of interest is an effective method for studying thinking styles and knowledge representation. While the power of probability sampling is to select a "truly random and statistically representative sample that will permit confident generalization from the sample to a larger population" [31, p.169], the focus of purposeful sampling is to select information-rich cases for in-depth study, in order to gain great insight into issues of central importance to the research [33]. In this work, we employ the method of *"Intensity Sampling",* whereby specific cases (expert designers) are chosen that intensely manifest the phenomenon of interest (information utilization and structuring as routine practice) [33]. Rather than extreme or unusual cases, excellent and prototypical examples of the phenomenon of interest are used to gain a deeper understanding into the practice of design. This method of sampling and analysis has been used in numerous studies in cognitive science [31,34,35] and engineering [36] to uncover valuable insights on complex phenomena and human experience through a detailed analysis of in-depth protocol studies on behavioral patterns, performance, and reflections.

Table 2. RELEVANT CHARACTERISTICS OF THE DESIGNERS

Participant Number	Design Experience	Position Title & Time in Position	Organization Size and Sector
D1	8 yrs	User Experience Lead, 2yr 11 mo	~ 51-200, mobile development & integration
D2	7 yrs	Product Designer, 6 mo	~ 51-200, managed hosting and web design
D3	3 yrs	CTO, 9 mo	~1-50, custom software development and design
D4	6 yrs	Founder & CEO 2 yrs 4 mo	~1-50, custom software development and design

2.1 Procedure

The designers were invited to attend 2-3 hour individual design sessions in a quiet and controlled environment. During these sessions, they were asked to engage with a hypothetical design challenge using information sheets provided to them. An overview of the study procedure can be found in Figure 1, and the following sections present each phase of the study in detail.

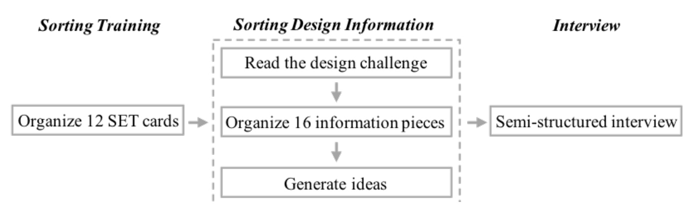


FIGURE 1. OVERVIEW OF THE STUDY PROCEDURE

2.1.1. Introduction and Training Phase. After a brief introduction to the purpose and procedures of the study, informed consent was obtained from all designers. Then, designers were briefed on the training task to be completed before other design activities. The training phase utilized 12 cards from the visual perception card game 'SET' (https://www.setgame.com/set). These cards were chosen because each card always has a unique combination of four features; Symbols (oval, squiggle or diamond), Colors (red, green or purple), Number of shapes (one, two or three), and Shading of the shape (solid, striped or empty). As such, the SET cards represented an abstraction of the ways that entities, such as design information, can vary and be grouped with one another. The purpose of this training session was to allow the designers to practice thinking about design information by their characteristics (symbols, colors, numbers, and shading) and how they can be grouped together using common traits to form archetypes. It was important that designers practiced this form of archetype grouping *removed* from the context of any design information to minimize any training effects in this study. During this training phase, no details of the design challenge and relevant information was provided, nor was there any explicit link made between actual information and the SET cards. All designers were provided with the same 12 cards (see Figure 2) in a randomly shuffled stack, and they were asked to organize the cards in a way that made sense to them by laying the cards out on a whiteboard and drawing their organization with whiteboard marker. The designers were asked to use any organizational scheme, annotations, and reasoning that they wanted to, and were asked to complete the task while thinking aloud and verbalizing their thought process.

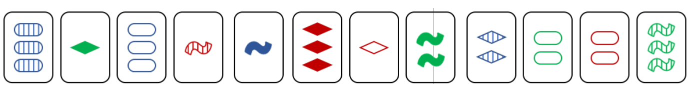


FIGURE 2. 12 SET CARDS PRESENTED TO EACH DESIGNER

2.1.2. The Design Challenge and Information Sheets. After the designers completed the training phase, they were introduced to the design challenge of developing solutions for reducing pedestrian accident rates. Designers were provided with a written design prompt that described the motivation and background behind the problem domain. The design task was: "*Your task is to develop concepts for a new, innovative product or system that will reduce pedestrian accident rates due to distraction from mobile devices.*". This task was intentionally open ended so that the participants were not limited to phone applications or system level designs, but instead could generate any ideas they wanted regardless of the complexity or scope. Once this task was understood and any questions were answered, the designers were provided with 15-minutes to familiarize themselves with 16 design information sheets (see Table 3). The researchers specifically developed and pilot tested the design information sheets for this design task using the framework described in Section 1.2.

In total, only 4 Information Dimensions were used for this study. The fifth dimension, Representation of Information, was not included in these information sheets since the form in which information is presented cannot be studied through an artificial research setting (i.e., by nature of the study, all information was asynchronous). Two information sheets were developed for each sublevel of the remaining 4 dimensions, resulting in the creation of 16 information sheets (4 dimensions x 2 levels x 2 sheets) for this study (see Table 3).

TABLE 3. THE INFORMATION DIMENSIONS AND TITLES OF EACH CORRESPONDING INFORMATION SHEET. COLOR CODES FOR EACH LEVEL ARE USED FOR DATA ANALYSIS

Dimension	Sublevel	Title of Design Information Sheets	
Source	Internal	Expected time to complete	Company culture
	External	Phone usage in traffic	General smart phone usage
Generality	Domain Specific	About Omaha	Distracted driving
	Cross-Cutting	Causes of distraction	Hearing and vision
Abstraction	Concrete	Frequency and time of accidents	Wearable technology & smartphone functionality
	Abstract	Non-driver related causes to car accidents	Behavioral change programs
Effectuation	Effectual	Available university departments	Available company resources
	Causal	City requirements	Dangerous driving

For example, four information sheets were created for the dimension "Abstraction of information"; two containing more abstract information (i.e. information about the use of behavioral change programs to influence behavior), and two containing detailed information about the hypothetical design task (i.e. information on the frequency and time of accidents). These information sheets were developed through a rigorous iterative process to ensure that each information sheet contained similar amounts of information, were roughly equivalent in length (~ 200 words each) and had minimal overlap with other information dimensions. For example, one Abstract information sheet detailed the Dangerous Driving habits that lead to pedestrian accidents, but did not provide statistical details like its concrete counterpart would. The full list of information sheets used for this study can be found at: https://www.unomaha.edu/college-of-information-science-and-technology/bridge/research/resources.php. During this stage, the designers were explicitly instructed to not yet start ideation but instead to focus on understanding each of the provided information sheets.

Next, similar to the SET task, the designers were asked to organize these information sheets in a way that made sense to them using any organizational schemes, annotations, and reasoning that they wanted to while verbalizing their thought process and using the whiteboard and marker to visualize it.

Once the designers had completed their organization of the sheets of information, they were asked to provide a high-level explanation and overview of the reasoning behind the organizational scheme to the researchers.

2.1.3. Idea Generation. Once the designers had explained their organization of the information sheets, they were given 20 minutes for idea generation. To reduce pressure on the designer, the researchers physically left the room during this time and they were free to brainstorm as many ideas as they could to address the design challenge. Once 20 minutes had passed, the researchers re-entered the study room and designers were asked to walk the researchers through their ideas and describe how they were related to the information sheets provided. For this paper, the focus was on the way that designers approach and interact with design information, thus the generated ideas and any relationships with those were not yet further considered.

2.1.4. Interview about Information Organization Experience. Lastly, a semi-structured interview was conducted to better understand how designers build a conceptual map of the design problem and information typically used during this stage. The following questions were asked during this interview:

1. Describe your general process of gathering information to help you solve a design problem.
2. How do you organize or group this information during this process?
3. How do you typically filter and use information to make design decisions?
4. What do you typically base your design decisions on?
5. To what extent does the availability of different types of information have an influence your design process?
6. Think about the information provided to you during the study. How similar were these to information you would normally gather during your design process?
7. Were you missing information to solve the challenge, if so, what information would you have liked to see?
8. What does your ideal design process look like compared to what typically happens at your work?

3. QUALITATIVE CODING ANALYSIS & RESULTS

In order to understand how designers organize information, a similar process was followed for collecting and analyzing the 12 playing cards and the 16 design information sheets. In both cases, the designer was provided with their materials and asked to organize it by drawing on a whiteboard while thinking-aloud, and then explain their organization to the researchers when they were done. This process was videotaped and audio-recorded, and their final output was photographed before being digitally recreated (see Table 4 and 5) to increase readability but otherwise remained unaltered. The videotaped process was analyzed to better understand their visual organization and to extract the thinking patterns and organizational strategies employed by the designers. The interviews were transcribed and analyzed for reoccurring patterns and themes using inductive content analysis. During the analysis, the material was analyzed with the following questions in mind: 1) how do designers visualize their organization? 2) what do they say their organizational strategies are? and 3) how do they typically organize design information in their everyday practice? The resulting patterns that emerged from these analyses are presented through the lens of these questions. They are detailed in the following sections in order of the tasks completed by the designers in this study.

3.1 Results of Card Organizing Task

An overview of the final visual organizations created by the designers can be found in Table 4. While all four designers had unique approaches, two preliminary patterns started to emerge:

3.1.1. Approaching the problem by understanding the space. Three designers began by laying out all 12 cards out on the table so that they could get an overview of what they were working with. These designers did not begin categorizing cards until they had viewed all 12 cards on the table, similar to the practice of understanding the problem space prior to beginning design activities. In contrast, one designer started categorizing cards as soon as they drew them from the stack while noting its features. As more cards (i.e. information) were revealed this designer dynamically adjusted their organization scheme by expanding, collapsing, and modifying categories.

3.1.2. Dynamically generated groups versus pre-conceptualized categories. Eventually, half of the designers chose a top-down approach (designer D1 and D3, see Table 4), in which they conceptualized a table or grid that incorporated all the existing card features along its axes, and cards were placed into their spot in accordance to their features. Designers who used this approach first identified the characteristics of the cards that distinguished them from others (e.g., Color and Shape) to enable logical categorization. This approach generated "gaps" in the organizational table because not all cells in the table could be filled by the available cards. Interestingly, both designers who chose this approach also showed how their "completed" grid would look if more cards had been available. For D1 that meant filling up the grid with colors of the cards that would go there, while D3 illustrated their expected shading sequence.

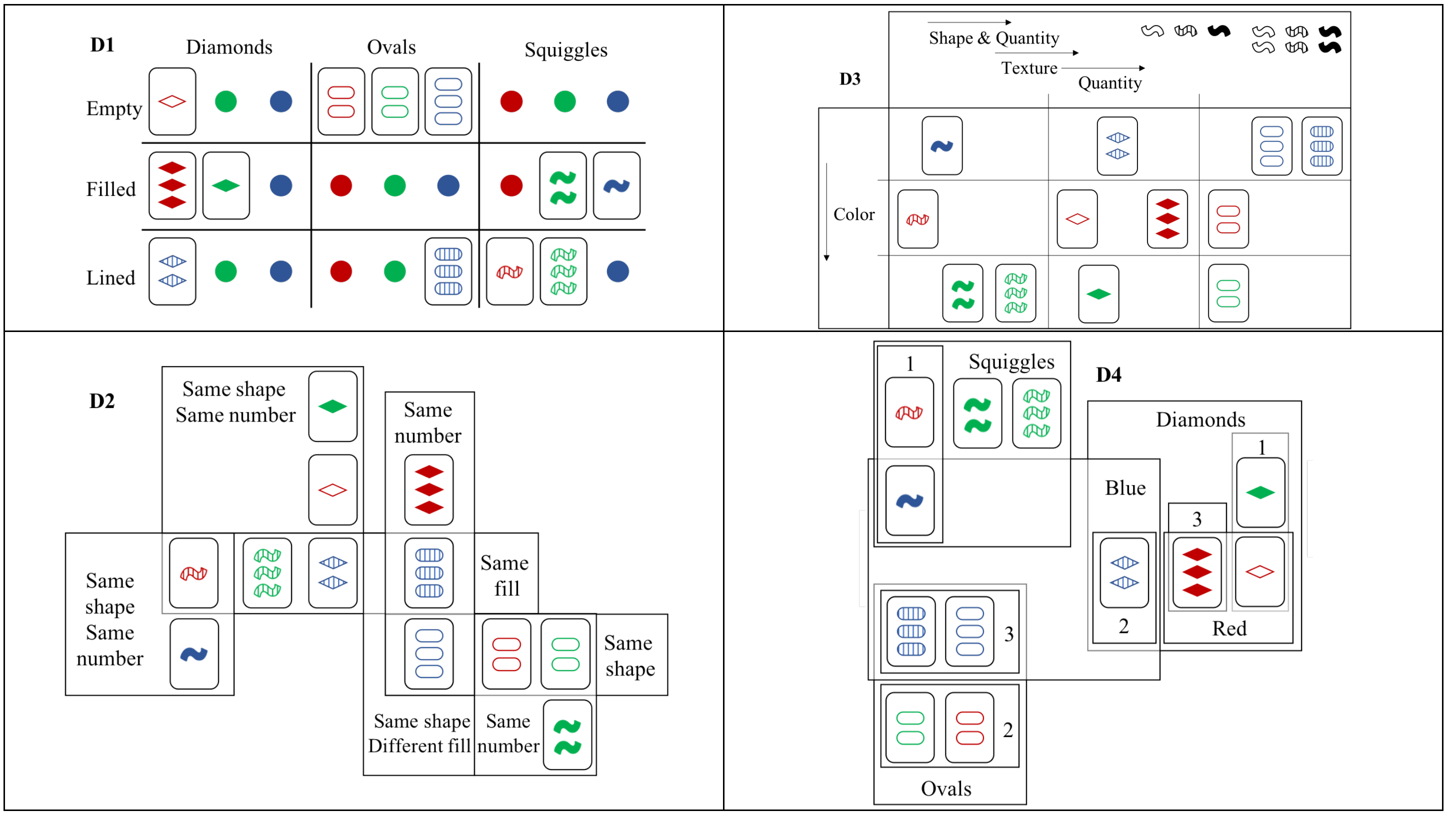
In contrast, the two other designers opted for a bottom-up approach (D2 and D4, see Table 4), in which they dynamically added groups and subgroups of shared characteristics as card features became apparent to them. Designers who used this approach analyzed each card separately and then used the cards' characteristics to draw similarities with existing groups that were already created, or made new groups if the card was sufficiently unique compared to existing cards. Using this approach, cards were placed in groups that often shared more than one characteristic (e.g. D2 created a group of *one*, *diamond* shapes but different *colors* and *shading*) since the focus was on generating groups which consisted of both high within-group similarity and high between-group difference.

While both approaches resulted in nested groups, the top-down approach revealed gaps or missing cards while the bottom-up approach highlighted the existing relationships between sets of card features as they organically emerged, without emphasis on exhaustive categorization or mutually exclusive groups.

3.2 Results of Design Information Organizing Task

A similar approach was taken for analyzing designers' behavior while organizing the provided design information sheets, resulting in three preliminary patterns. An overview of the resulting visual organization can be found in Table 5.

TABLE 4. ORGANIZATION OF THE 12 SET CARDS BY THE DESIGNERS



3.2.1. Visual organizational scheme.

Designers found it difficult to inhibit organizing the provided design information sheets while they were familiarizing themselves with the relevant information. Overall, all designers shared a similar initial approach of placing the information sheets in dynamically created categories, after which they further adapted it to fit their individual needs. Typically, the designers grouped the 16 information sheets into five categories consisting of 2 to 5 information sheets, as best exemplified by D2 (see Figure 3).

After this shared 'baseline', each designer personalized their outputs. Most notably, D4 deviated from this by having seven groups, including one with a single card ("Available university departments") in the category named "Client", despite the design brief not explicitly stating a client. While D1 and D2 shared a tabular structure, both D3 and D4 needed more dimensions to accommodate the relationships they had drawn between the information sheets. For instance, D3 created sub scales within some groups to represent the internal structure of the group, while D4 created subgroups ("Dangerous driving" within "Driving") and an overlapping group ("Distraction"). In addition, D4 also represented relationships between the different groups using arrows to indicate how, for example, "Generic information" would inform the "Requirements", which in turn would inform the "Client", who also had a direct bi-directional relationship with "Generic information" (see D4 in Table 5).

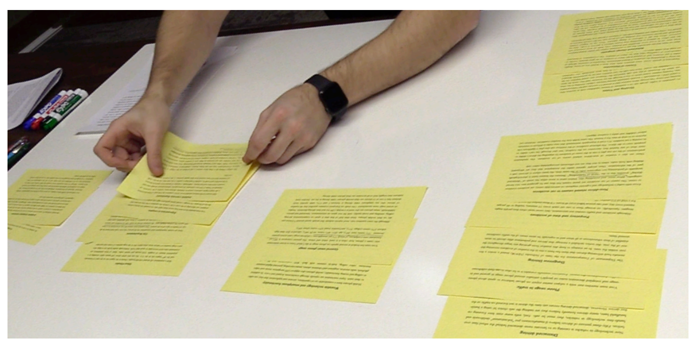
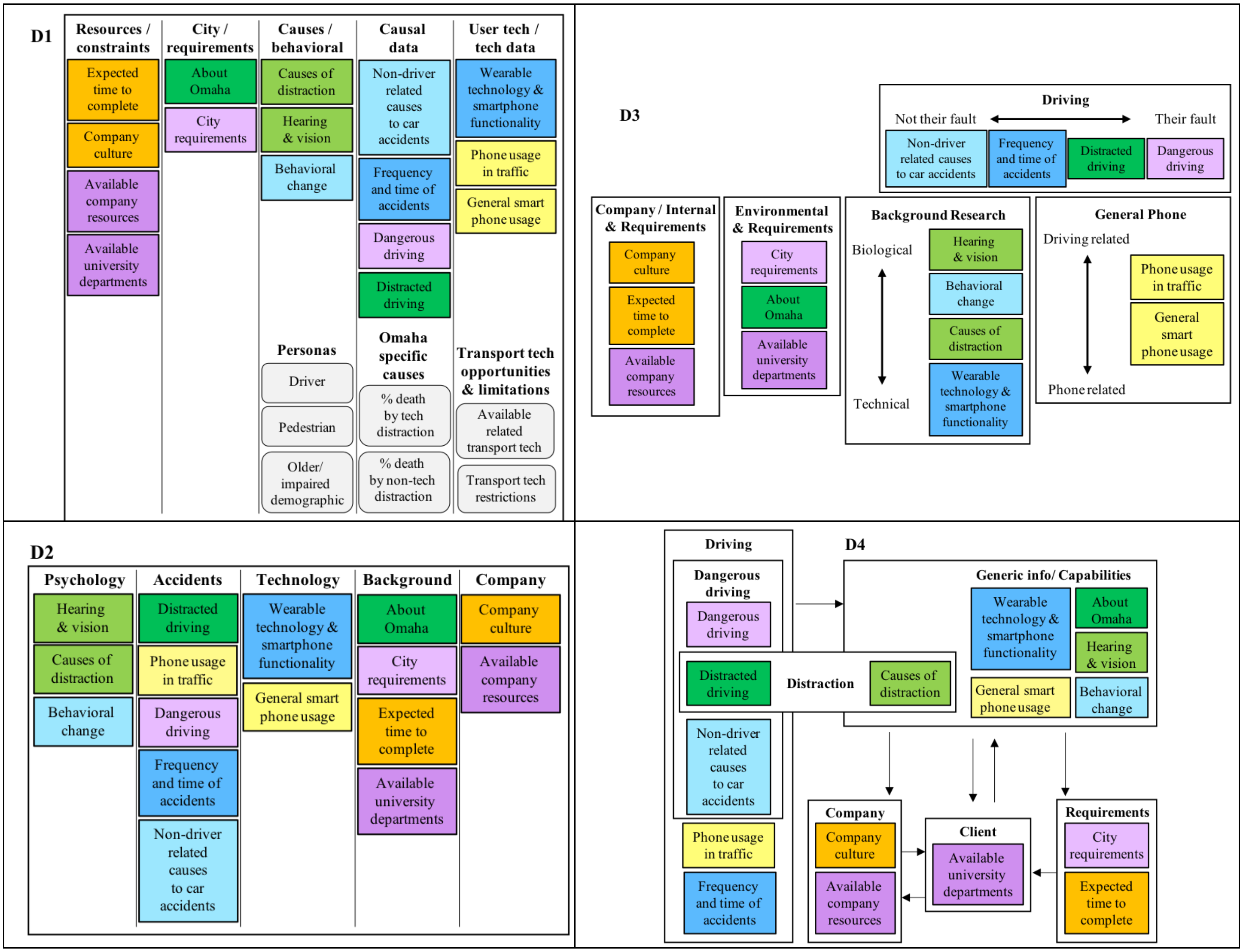


FIGURE 3. D2'S INITIAL INFORMATION SHEETS GROUPING

3.2.2. The role of design goals, constraints and resources in evaluating information.

Broadly speaking, designers grouped information as being either something that they could do (capability or resource), something they could not do (limitation or constraint), or something they had to meet (goal, need or requirement). This enabled the designers to create a high-level distinction between information that was directly related or relevant to the problem and information that was nice to know but not critical to the problem. Interestingly, this was not discernable from their category names, as these would, at first glance, appear to be content-based. Instead, these became apparent as designers explained their organization to the researchers. This is best illustrated by the creation of a 'background research' category by three designers.

TABLE 5. ORGANIZATION OF THE DESIGN INFORMATION SHEETS BY THE DESIGNERS. COLORED RECTANGLES CORRESPOND TO THE COLOR CODING OF THE DESIGN INFORMATION PROVIDED IN TABLE 3



Although this might appear to indicate irrelevant information, this actually contained information that was used to frame the problem. For example, D2 used this background information as a way to, in their words, "set the scene" for the project, while D3 and D4 considered their background category more as a way to capture the capabilities and constraints of the humans and technology involved in the project. Indeed, all designers highlighted the importance of identifying and leveraging project requirements (or needs), constraints (or limitations), and capabilities (or resources). These factors were used by the designers to scope the project, evaluate the usefulness or relevance of each information sheet, and where to direct their attention to find potential solutions to the problem. The relevance of each card depended on the purpose each designer assigned to it. For example, D2 mentioned that information about the imaginary company that they hypothetically worked for during the design challenge was something that they would keep in the back of their mind but was not something that they considered very relevant. In contrast, D4 considered this hypothetical company information to be crucial to determining what solutions they could (not) develop, thus simultaneously acting as both capabilities and constraints to their potential solution(s). They expanded on this by explaining how company and generic information informed their capabilities were informed by, while client information informed their requirements.

While three designers focused on only using the information provided to them in the study, D1 went further by also wanting to consider information that was not directly available to them. Specifically, D1 wanted to use their "Causes/behavioral" and "Causal data" categories to find potential solutions, but deemed the provided information sheets to be too general in nature. To express the type of information they would have liked to see included in the study, they created hypothetical information sheets with topics (indicated as grey rounded squares in Table 5).

These sheets described information that was more directly related to the design problem, such as the specific details about accidents that happened in that particular city. They also included a "Persona" card, which would contain patterns of characteristics shared between people who have been in the situations described by the project brief. The designer explained that they often employ personas at their company as a tool to turn general information into actionable insights. None of the other designers, who all worked at different companies, mentioned the use of personas. Additionally, the designers observed that the data was skewed towards quantitative data, and they expressed a desire to see more qualitative data, preferably from actual users, or in this case, people who had been in the design challenge situations.

3.2.3. Guiding role of the design brief. In addition to the requirements, constraints and capabilities found in the provided information sheets, designers often referred back to the design challenge to guide their focus as they went through the information sheets. As the project brief did not explicitly state a client or user, two designers filled these roles in to reduce complexity. D1 designated the city as the client and "people and people's behavior" as the customer, while D4 considered the university as the client. All four designers leaned more towards pedestrian-oriented solutions as this was outlined in the brief, although some did observe a discrepancy with the sheets, which focused more on the driver. Where D1 took a broad view of the situation by targeting "the experience of walking around", D3 and D4 focused primarily on distracted pedestrians. D3 made a conscious effort to focus on pedestrians over distracted drivers based on information in the project brief: "I stuck closely to [the design brief] when they said that they're looking for devices for when students are walking around and they trip and fall and things like that". This pattern of behavior highlights the importance of the initial framing of the design challenge through the use of the design prompt. Overall, designers considered the importance and utility of each sheet of information through the lens of who they identified as their primary stakeholder, placing more or less importance on different sheets of information depending on its perceived utility. Thus, information sheets provided during this design exploration stage can be understood as dynamic inputs to the design process, sensitive to the context that the designer finds themselves in.

3.3 Results of the interviews

The results of the semi-structured interviews at the end of the study provided insights into the findings from the previous section. Emergent patterns from designers' retrospective reflection of the activity provide a deeper understanding of their information structuring and utilization behaviors during design activities. These patterns are discussed in the following sections.

3.3.1. Offloading cognition onto external tools. All four designers discussed some form of externalizing information during their typical design activities, but described different means of doing so. While D1 did not identify a personal organization style, they highlighted the value of a customer journey map. In this designer's everyday design practice, these maps are generated as quickly and with as many relevant stakeholders as possible so that it can serve as a guiding document throughout the project. D3 also mentioned the use of a collaborative document-editing tool, but they relied more on mentally aggregating relevant information into actionable heuristics. They did the same for the design challenge in this study, stating that they had generated a mental rule that the solution "should be something to make pedestrians run into less things and make it so that people with disabilities can use it". Both D2 and D4 used lists to organize information. D2 kept more "high-level bulleted lists of the key things about the project that we need to be addressing", while D4 depended heavily on electronic lists to keep track of all kinds of information.

3.3.2. Determining design goals. All designers stressed the importance of user or customer feedback and usability testing for providing focus and priorities throughout the design process. Additionally, they also highlighted the role of goals, requirements and constraints as a means for determining the solution space. As D1 puts it "We generally like to do an analysis of any limitations because then we know the frame we can work in". The process in which designers seek specific information was also influenced by their role in the company. This is best exemplified by D3 and D4, who work in the same company but have different responsibilities. Both designers seek information to gain an understanding of the solution space and consequentially scope the project. As D3 (similar to D1 and D2, although for different companies) primarily operated in the design stage and secondarily in the development stage, they sought user requirements (through usability testing and user feedback), while D4 appeared to predominately work in the proposal stage that preceded the design stage and thus was more concerned with technological capabilities and client relations.

Procedurally, the information gathering process for D4 began with reaching out to experts on the topic to acquire know-how and advice on what information is important and where to find it. In addition, they would supplement this with the resources that they found on the internet that fit the requirements. After narrowing down the top three best options, D4 would test each option themselves to determine fit and viability for this project before discussing the direction of the project with the client. In contrast to D4's solution oriented process, D3 indicated that their main stakeholder was the customer or end user. When asked about what design decisions are typically based on, D3 responded with "It's pretty much solely from customer feedback and general usability guidelines". Their objective was to understand people's needs in order to determine what the core problem was and who the end users were, typically through desk research and in-person interviews. Therefore, they pointed at the use of the project brief and project goals as guiding direction in the very early stages of the project, but then using customer goals to validate and narrow down solutions as the project progresses.

3.3.3. Knowledge transfer. The value of expertise was brought up by the designers as valuable for both within in a domain as well as something that carried over between projects. For D1, expertise took the form of a knowledge library and a set of core features required for applications in their domain of expertise: "One of my main specialties is mobile banking. So there's a lot of core features that you definitely need in a mobile banking app, and we've got a library of competitor analyses in the mobile banking space which is really nice. So we know all of the major banks and what primary features that they offer. We generally know what you cannot ignore as a mobile banking app when you're putting it out on the market". In the case of D3 and D4, a prior experience with a client led them to create a template that they required their future clients to fill out prior to the design engagement. This was used to facilitate discussion on the design process, as they had found out that clients often lack knowledge about the design process and the value of usability testing.

3.3.4. Iterative information seeking. Although D3 and D4 preferred to do the bulk of the project design prior to development and make small adjustments while developing, all designers used Minimum Viable Products (MVP) in their design process. D2 used customer information to determine what should be part of each MVP release, while D1 expressed a preference for quickly and frequently building testable prototypes to acquire customer feedback to validate or disprove hypotheses and patterns. This was echoed by D2, who used the usability tests to identify patterns of people struggling with something as the basis for improvement for the next round of testing. D1 summarized their general process of information filtering and management as "We're expanding out as we're always trying to learn more as we're going, but then always going back to the problem we're actually trying to solve, and how does this new information relate to how we're approaching the problem".

4. DISCUSSION

The main purpose of this study was to investigate the strategies used by expert designers to organize relevant information during a design task. The main findings of this study are as follows:

- Regardless of domain (SET cards versus information sheets), designers displayed similar patterns in how they approached and structured information, although their outcomes differed.
- Designers considered the information space either from an organic approach in which categories were dynamically formed as information was encountered, versus a more holistic approach in which the full available information space was considered prior to forming categories.
- Information was evaluated based on its ability to serve as a project or user requirement, constraint or resource.
- Designers "scaffold" information by employing knowledge transfer tools such as heuristics, standardized project templates, lists, and journey maps to structure and keep track of complex information within and across projects.

The findings of this study provide further evidence for the importance of goals, constraints and resources on how designers frame their information organization strategies [37]. To reduce complexity and cognitive load, designers formulate generic approaches that they can apply across domains and projects. These findings support prior research that showed evidence for the transfer of skills, competences, principles and reasoning through generative heritages [38]. While all designers observed general design best practices, they augmented these with individual and company experience to create their own unique processes. One designer (D3) was found to apply their typical style of reasoning in the design challenge as well, transforming the information provided into explicitly formulated prescriptive design principles [18]. These principles guided the direction of the design task and shaped how they evaluated subsequent information. Another designer (D2) adopted more descriptive design principles [18], using them more as a way to understand the space than to guide action. The use of heuristics has been noted in prior research, which cite the primary purpose of heuristics as a way to move the designer into a more creative mindset in which they are able to explore the space for potential solutions [31]. These results demonstrate the creation and use of heuristics in the information structuring phase prior to idea generation.

5. STUDY LIMITATIONS AND FUTURE WORK

This study builds on previous work investigating the types of information that designers use during the design process using reflective interviews [24]. To better understand how designers utilize these different types of information, this study set out to investigate how designers approach, structure and organize information in a more controlled setting. Doing so simplified the situation to one where the designer was the only person working on the (hypothetical) design challenge, information was already provided to them, and they did not interact with a client or user. While this method reduces the effect of potential confounds, it does not accurately reflect everyday design experiences. One notable difference is that this study took place at one moment in time, while knowledge structuring in the real world takes place over a period of several weeks, months or even years. Therefore, the results of this study would benefit from supplementation of longitudinal and field data.

Additionally, the information sheets provided to the designers was based on the Typological Framework of Design Information developed in previous work [24], so that they would reflect the types of information designers would typically encounter. Indeed, the framework proved helpful in creating a representative information space, as creating truly mutually exclusive categories of information is not feasible, nor is it representative of information encountered during design practice. Future work could look into expanding the Typological Framework of Design Information by investigating how the framework relates to designers and their daily practice. This would strengthen and extend the practical applicability of the framework beyond theoretical implications. Additionally, future work should analyze the ideas generated by the designers during the ideation phase to identify any transfer of information or expertise during this process.

Lastly, the sample size of this study is relatively small. This is a result of the Intensity Sampling method [33], which was purposefully employed to collect detailed insight into expert designers' strategies, reasoning, and methods for engaging with large volumes of relevant information early in the design process. This targeted, in-depth interaction involved prototypical designers with at least three years of experience working in the design and development field. Current efforts are undertaken to incorporate the design cognition of expert designers in other fields, such as web design and development.

6. CONCLUSION

This study provides preliminary support for the existence of shared underlying patterns in how expert designers approach, organize and utilize information in the early phases of the design process. The designers were found to evaluate the relevance of information for its ability to inform the project or user requirements, constraints or resources. Although all designers sought to turn the available data into actionable insight, their individual differences and experiences led to unique results. These findings contribute to the understanding of how designers navigate complex information to generate creative solutions, and highlight the value of design expertise in this process.

7. ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1755864. We would also like to thank our research group, the BRIDGE lab (https://www.unomaha.edu/college-of-information-science-and-technology/bridge), and our participants for their help in this project.

8. REFERENCES

[1] Eppler, M. J., and Mengis, J., 2004, "The Concept of Information Overload: A Review of Literature from Organization Science, Accounting, Marketing, MIS, and Related Disciplines," The Information Society, **20**(5), pp. 325–344.

[2] Kim, J., and Ryu, H., 2014, "A Design Thinking Rationality Framework: Framing and Solving Design Problems in Early Concept Generation," Human–Computer Interaction, **29**(5–6), pp. 516–553.

[3] Sarasvathy, S. D., 2001, "Causation And Effectuation: Toward A Theoretical Shift From Economic Inevitability To Entrepreneurial Contingency," Academy of Management Review, **26**(3), pp. 243–263.

[4] Ball, L. J., St. Bt Evans, J., Dennis, I., and Ormerod, T. C., 1997, "Problem-Solving Strategies and Expertise in Engineering Design," Thinking & Reasoning, **3**(4), pp. 247–270.

[5] Herring, S. R., Chang, C.-C., Krantzler, J., and Bailey, B. P., 2009, "Getting Inspired!: Understanding How and Why Examples Are Used in Creative Design Practice," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, New York, NY, USA, pp. 87–96.

[6] Jansson, D., and Smith, S., 1991, "Design Fixation," Design Studies, **12**(1), pp. 3–11.

[7] Crilly, N., and Cardoso, C., 2017, "Where next for Research on Fixation, Inspiration and Creativity in Design?," Design Studies, **50**, pp. 1–38.

[8] Gero, J. S., 1990, "Design Prototypes: A Knowledge Representation Schema for Design," 1, **11**(4), pp. 26–26.

[9] Dorst, K., and Vermaas, P. E., 2005, "John Gero's Function-Behaviour-Structure Model of Designing: A Critical Analysis," Res Eng Design, **16**(1), pp. 17–26.

[10] Wiley, J., 1998, "Expertise as Mental Set: The Effects of Domain Knowledge in Creative Problem Solving," Memory & Cognition, **26**, pp. 716–730.

[11] Finke, R. A., Ward, T. B., and Smith, S. M., 1992, *Creative Cognition: Theory, Research, and Applications*, The MIT Press, Cambridge, MA, US.

[12] Hunter, S. T., Bedell-Avers, K. E., Hunsicker, C. M., Mumford, M. D., and Ligon, G. S., 2008, "Applying Multiple Knowledge Structures in Creative Thought: Effects on Idea Generation and Problem-Solving," Creativity Research Journal, **20**(2), pp. 137–154.

[13] Hatchuel, A., Le Masson, P., and Weil, B., 2017, "C-K Theory: Modelling Creative Thinking and Its Impact on Research," *Creativity, Design Thinking and Interdisciplinarity*, F. Darbellay, Z. Moody, and T. Lubart, eds., Springer Singapore, Singapore, pp. 169–183.

[14] Brun, J., Le Masson, P., and Weil, B., 2018, "Getting Inspiration or Creating Inspiration? The Role of Knowledge Structures in Idea Generation," *Proceedings of the DESIGN 2018 15th International Design Conference*, Dubrovnik, Croatia, pp. 1793–1804.

[15] Phelps, R. H., and Shanteau, J., 1978, "Livestock Judges: How Much Information Can an Expert Use?," Organizational Behavior and Human Performance, **21**(2), pp. 209–219.

[16] Gobet, F., and Simon, H. A., 1998, "Expert Chess Memory: Revisiting the Chunking Hypothesis," Memory, **6**(3), pp. 225–255.

[17] Schoenfeld, A. H., and Herrmann, D. J., 1982, "Problem Perception and Knowledge Structure in Expert and Novice Mathematical Problem Solvers," Journal of Experimental Psychology: Learning, Memory, and Cognition, **8**(5), pp. 484–494.

[18] Fu, K. K., Yang, M. C., and Wood, K. L., 2016, "Design Principles: Literature Review, Analysis, and Future Directions," Journal of Mechanical Design, **138**(10), p. 101103.

[19] Korhonen, P. J., Malo, P., Pajala, T., Ravaja, N., Somervuori, O., and Wallenius, J., 2018, "Context Matters: The Impact of Product Type, Emotional Attachment and Information Overload on Choice Quality," European Journal of Operational Research, **264**(1), pp. 270–279.

[20] Gielnik, M. M., Frese, M., Graf, J. M., and Kampschulte, A., 2012, "Creativity in the Opportunity Identification Process and the Moderating Effect of Diversity of Information," Journal of Business Venturing, **27**(5), pp. 559–576.

[21] Spink, A., and Cole, C., 2006, "Human Information Behavior: Integrating Diverse Approaches and Information Use," Journal of the American Society for Information Science and Technology, **57**(1), pp. 25–35.

[22] Heisig, P., Caldwell, N. H. M., Grebici, K., and Clarkson, P. J., 2010, "Exploring Knowledge and Information Needs in Engineering from the Past and for the Future – Results from a Survey," Design Studies, **31**(5), pp. 499–532.

[23] Cole, C. A., and Gaeth, G. J., 1990, "Cognitive and Age-Related Differences in the Ability to Use Nutritional Information in a Complex Environment," Journal of Marketing Research, **27**(2), pp. 175–184.

[24] Lumbard, K., Abid, A., Toh, C. A., and Germonprez, M., 2018, "Knowing and Designing: Understanding Information Use in Design Industry Through the Lens of Information Archetypes,"

Proceedings of the 51st Hawaii International Conference on System Sciences, Big Island, HI, pp. 4065–4074.

[25] Doty, D. H., and Glick, W. H., 1994, “Typologies as a Unique Form of Theory Building: Toward Improved Understanding and Modeling,” Acad. Manage. Rev, **19**(2), pp. 230–251.

[26] Brandtzæg, P. B., 2010, “Towards a Unified Media-User Typology (MUT): A Meta-Analysis and Review of the Research Literature on Media-User Typologies,” Computers in Human Behavior, **26**(5), pp. 940–956.

[27] Büchel, F., Humprecht, E., Castro-Herrero, L., Engesser, S., and Brüggemann, M., 2016, “Building Empirical Typologies with QCA: Toward a Classification of Media Systems,” The International Journal of Press/Politics, **21**(3), pp. 209–232.

[28] Mintzberg, H., 1989, “The Structuring of Organizations,” *Readings in Strategic Management*, Springer, pp. 322–352.

[29] O’Raghallaigh, P., Sammon, D., and Murphy, C., 2010, “Theory-Building Using Typologies--A Worked Example of Building a Typology of Knowledge Activities for Innovation,” *Proceedings of the 2010 Conference on Bridging the Socio-Technical Gap in Decision Support Systems: Challenges for the Next Decade*, University of Lisbon, Portugal, pp. 371–382.

[30] Mayring, P., 2004, “Qualitative Content Analysis,” *A Companion to Qualitative Research*, U. Flick, E. Kardoff, and I. Steinke, eds., Sage Publications, Thousand Oaks, CA, pp. 266–269.

[31] Yilmaz, S., and Seifert, C., 2011, “Creativity through Design Heuristics: A Case Study of Expert Product Design,” Design Studies, **32**(4), pp. 384–415.

[32] Saiedian, H., and Dale, R., 2000, “Requirements Engineering: Making the Connection between the Software Developer and Customer,” Information and Software Technology, **42**(6), pp. 419–428.

[33] Patton, M. Q., 1990, *Qualitative Evaluation and Research Methods, 2nd Ed*, Sage Publications, Inc, Thousand Oaks, CA, US.

[34] Chase, W. G., and Simon, H. A., 1973, “The Mind’s Eye in Chess,” *Proceedings of the Eighth Annual Carnegie Symposium on Cognition*, Carnegie-Mellon University, Pittsburgh, Pennsylvania, pp. 215–281.

[35] Morais, A. S., Olsson, H., and Schooler, L. J., 2013, “Mapping the Structure of Semantic Memory,” Cognitive Science, **37**(1), pp. 125–145.

[36] Tomko, M., Schwartz, A., Newstetter, W., Alemán, M., Nagel, R., and Linsey, J., 2018, “‘A Makerspace Is More Than Just a Room Full of Tools’: What Learning Looks Like for Female Students in Makerspaces,” American Society of Mechanical Engineers, p. V007T06A036-V007T06A036.

[37] Dorst, K., and Cross, N., 2001, “Creativity in the Design Process: Co-Evolution of Problem–Solution,” Design Stud., **22**, pp. 425–437.

[38] Carvajal Pérez, D., Araud, A., Chaperon, V., Le Masson, P., and Weil, B., 2018, “Generative Heritage: Driving Generativity Through Knowledge Structures In Creative Industries. Lessons From Cuisine,” *DS 92: Proceedings of the DESIGN 2018 15th International Design Conference*, pp. 1523–1534.