Design Frames: A Narrative and Network Approach

by

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Abstract

In today's increasingly interconnected world, we are facing challenges that are unprecedented in complexity and scale. At the same time, there is a growing awareness about the inadequacy and obsolescence of old and "best practice" strategies for solving these vexing challenges. The inadequacy of solutions that work within existing frames of thought has generated a renewed interest in research on problem-solving and creativity. While originally initiated in cognitive psychology, cognitive science, and artificial intelligence, research on the mechanisms underlying the creative process has become a central topic in a variety of other disciplines, such as management, business, and healthcare. As a result, public and private organizations are increasingly turning to designers to bring a fresh perspective to the challenges they are facing.

As designers become more engaged in solving large-scale and intricate questions, the need for developing systematic approaches to design and their deployment in both design education and practice becomes more evident. Developing methods that function successfully within design environments requires a thorough understanding of problem-solving approaches in design. In recent years, a growing number of studies have addressed this question by investigating designers' working practices in the lab or in the field. One of the most influential concepts in studying the design process is the constructivist notion of "framing" (Schön, 1983) which suggests that the core activity in the design process is constructing a frame: a perspective

or a point of view that allows the designers to tackle a problem in a vague and indefinite design situation. While the frame's concept has been central in studying the design process, its formal definition remains vague and unclear.

This dissertation aims to shed new light on the concept of frame by proposing two models for systematically describing their structure. These models can be used to make the frames constructed during the design process more explicit by following their development throughout the design process. Building upon two language-based representation modes (stories and semantic networks), the models employed in this dissertation facilitate the description of frames and the analysis of the design process by tracking the shifts in the content and structure of frames. These models were utilized in three verbal protocol studies to investigate different aspects of framing in design. In these studies, we explored the strategies for managing the multiplicity of the frames (chapter 2), reframing process (chapter 3), and divergent and convergent patterns (chapter 4) during the design process.

The contributions of this dissertation are both theoretical and practical. Models and results presented in this dissertation open up new paths future research on the use of framing in design, thereby informing design education and practice. Models presented in this work address the gap in the formal description of frames in the existing literature. The concepts of narrative and network show a flexible way to describe frames that can be utilized to identify and describe frames both qualitatively and quantitatively. On the other hand, the description of frames as a system of stories (narrative model) and concepts (network model) allows the frame to be analyzed on both meta-level (network and narratives) and the component level (concepts and stories). This systematic perspective suggests an interactive analysis of frames in which shifts in the frame level can be traced to the constituent elements of the design process and vice versa.

Chapter 1 Introduction

In an increasingly interconnected world, we are facing challenges that are unprecedented in complexity and scale. To meet these challenges, a new appreciation has emerged of designers' ability to imagine creative solutions. The need for innovative solutions has renewed interest in exploring the processes through which new and creative ideas are generated. While initiated within the discourse of psychology and cognitive science, research on the mechanisms underlying the creative process have become a topic of interest for a variety of disciplines including but not limited to management, business, and healthcare. A growing number of books and articles have been published in the past few years to foster creativity in individuals and in organizations.

Designers are known for their capacity to create innovative solutions to unique problems. Hence, the methods used by designers has been studied as an epistemological approach for creativity and innovation across many fields. This interest in design has been manifested in two interconnected discourses. While the designerly thinking discourse is concerned with understanding the skills and competencies of designers, the design thinking discourse promotes the use of design skills for solving problems by involving designers in contexts outside the conventional boundaries of the design practice and teaching design methods to practitioners without a design background (Archer, 1979; Cross, 1982; Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013). Design thinking has been adopted by disciplines such as management and business, as a promising model for finding innovative approaches that go beyond the established strategic models (Martin, 2009).

Design thinking aims to expand the notion of design from making physical products to a model for approaching social and organizational problems (Norman, 2010). While job titles in the previous discourse referred to the medium of design (e.g. architect, industrial designer, graphic designers, interior designer), the new titles describe the broader context of design (e.g. user experience designer, service designer, interaction designer). Design companies such as IDEO and Frog Design Inc. that were originally founded as industrial design companies have rebranded themselves as innovation companies and became involved in large-scale and systemic problems ranging from redefining the voting system in Los Angeles County to cutting food waste in restaurants. More recently, large architecture firms have started embracing the approach by defining the environment as the context for experience and interaction.

This expanded interest in design has opened new opportunities for designers. However, educators and practitioners are nevertheless concerned that designers are not typically trained to deal with large-scale systems that entail social and technological complexities (Norman, 2010). While designers are well experienced in organizing objects and shapes, they may not be as adept in dealing with complex systems consisting of people, machines, and environments that are interconnected on multiple levels. Working with such systems poses a challenge to the existing design methods that are often based on the intuition and experience of designers.

In the past few years, design researchers and educators have attempted to address this issue in different ways. First, to deal with these complex situations, designers must be able to gain a deeper knowledge of human behavior, society, technology, and business. On one hand, architecture and design schools are adding social science, psychology, business, and technology courses to supplement the conventional design education that relies normally on design studio training and technical courses. One the other hand, design practices are integrating anthropologists, social and behavioral scientists, and business leaders into their design teams to diversify their skills for dealing with complex socio-technical challenges.

Finally, new methods and models have been developed to help designers in dealing with complex design situations. Tackling socio-technical problems requires using a variety of models that allow designers to organize the facts of the situation. The goal is not to find and apply the right model but to shed light on the phenomenon from different perspectives (Page, 2018). Design educators and practitioners have developed a variety of models and methods to structure and facilitate this process (Vijay, 2012; Hanington, 2012).

A number of these methods are aimed at facilitating the processes by which designers make sense of the situation. This initial interaction between the designer and the design situation is described with terms such as problem structuring, definition, construction, and framing based on epistemological assumptions of the study. The positivist paradigm[1] (mainly represented by Simon's theory of technical rationality) often uses the term problem structuring while the

1 The positivist school of thought aims to achieve an objective explanation and prediction of the world using the methods of natural science such as hypothetico-deductive logic and inductive reasoning.

constructivist paradigm[2] (mainly represented with Schön's theory of reflective practice) uses the term framing. In the positivist model, the design is a process of rational problem-solving (Dorst & Dijkuis, 1995) in which designers structure *ill-structured problems* by *decomposing* them into smaller components and searching within the solution space to find optimized solutions for these *well-structured problems.* Taking a constructivist perspective, the theory of reflective practice proposed that designers construct problems by *framing* the situation. Problems are not objectively presented to the designer but constructed through a process of action and reflection with the situation which results in the creation of a *frame*.

Framing of a situation determines the direction of design solutions. Consider the following example. Millions of birds get killed every year by flying into building windows (Machtans, Wedeles & Bayne, 2013). One way to look at the situation is to focus on the transparent window's invisibility to birds. In this framing, the goal of design is to create a *bird-proof* window that prevents the collision by making the glass visible to the bird. Instead of avoiding the crash, one can focus on creating a *bird-safe* window that minimizes the collision's damage. The first framing directs the design process to develop strategies that make the glass surface visible to birds (e.g., adding visible patterns to the window). The second one leads to solutions that make the collision between the bird and the window less harmful (e.g., installing a mesh on the window).

The ability to frame a problem from a situation has been recognized as a core competency of experienced and effective designers (Dorst, 2011), a key component of the

2 The constructivist school of thought rejects the possibility of objective knowledge since it is through an interaction between the world and the learner's existing experiences that knowledge is constructed.

problem-solving process (Schön, 1984) and central to creativity and innovation (Norman & Verganti, 2013; Dorst, 2015). The existing research into framing has investigated the role of framing in the design process (Valkenburg & Dorst, 1998; Gao & Kvan, 2004; Dorst & Cross, 2001), the strategies and tools to support the framing process (Paton & Dorst, 2011; Kokotovich, 2014; Lloyd & Oak, 2018) and the tensions between frames held by different stakeholders and the ways in which such differences are resolved (Stumpff & McDonnell, 2012; Stompff, Smulders & Henze, 2016; McDonnell, 2018; Hey, Joyce & Beckman, 2007).

The existing research has addressed the significance of framing in the design process. However, the concept of the frame itself seems to be vaguely defined, and the systematic presentation of the content and structure of frames is missing. While the frame is described as a perspective or a point of view that allows the designers to tackle the problem, models for describing them have remained rather undeveloped. While notions of point-of-view (Kolko, 2010) or metaphor (Schön, 1979; Pee, Dorst & van der Bijl-Brouwer, 2015) are useful ways for communicating the concept of frame, they are too broad and ambiguous to allow any particular and concrete definition to be obtained. This dissertation is an attempt to fill this gap by proposing formal models which allow the identification and presentation of frames. Such specificity allows new ways of describing and understanding the design process that will be explored throughout the following chapters.

Dissertation Overview

The purpose of this dissertation is two-fold: 1) to present models that make it possible to describe and analyze frames in a design process and 2) to utilize these frameworks in a series of empirical studies to gain insight into the design process (Figure 1.1).

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Figure 1.1. The Structure of Dissertation

Chapter 2 starts with an overview of the existing research on defining and modeling frames in design. This review suggests that while a theoretical basis for framing exists in the literature, a concrete understanding of the concept of frame is missing from the constructivist perspective of design. To address this issue, we adopt the notion of a frame as a representation of the designer's knowledge of the situation and propose narratives and networks as two models of describing frames. Both narratives and networks models represent knowledge as a system of elements and relations: network as a system of concepts and narrative as a system of stories.

In the following chapters, these models are used to conduct a series of empirical studies of the design process. These studies rely on protocol analysis, a widely used observational method for recording and examining behavior, sketches, and verbalizations that designers generate during the design process to gain insight into the process.

The details of these studies will be described in greater detail in the following chapters: a brief overview is provided here. Data for the protocol analysis were collected from 16 ideation sessions with 32 graduate students from four design disciplines (architecture, human-computer interaction, integrative design, and urban design). In each design session, two participants from different disciplines were given a design brief regarding the safety lights on campus and were asked to generate as many ideas as possible in 45 minutes. Each ideation session was voice-recorded, transcribed, and analyzed using a mixed-method approach based on the narrative model (chapters 3 and 4) and the network approach (chapter 5) to explore questions regarding different aspects of framing.

Chapter 3 starts with a review of the literature related to the use of multiple frames in the design process as a mechanism to deal with the complexity of the designs. While the existing studies emphasize the non-linearity of the framing process, and the multiplicity of frames in the design process, the strategies that designers utilize to manage frames during the design process have not been explored. In this chapter, we build a coding scheme based on the narrative model, which is used to identify frames and their development over the course of the design process. Using the results of this analysis, we identified parallel and serial strategies for frame development and diffused and concentrated strategies for frame generation.

In chapter 4, we will specifically focus on the process of reframing during the design process. Reframing is the process of replacing existing ways of understanding a situation with new ones. Existing literature on reframing suggests surprise, frame conflict, and dissatisfaction as the underlying processes that trigger reframing. In this chapter, we use the narrative approach to look at reframing through a new lens: dismantling of an old narrative and coming up with a new narrative. To investigate this process, design activities in two reframing episodes were analyzed using a coding scheme that identified different modes of reflections in the reframing process and the ways in which they contribute to creating a crisis for the narrative and driving designers to initiate a new narrative.

In Chapter 5, we move to the network model to study the divergent and convergent processes in design. This chapter begins with an overview of the literature of dual-process models of cognition[3] and their relevance to the design process. Using the network model, we present an approach for constructing semantic networks from the conversation between designers. Design protocols were analyzed using this approach to identify divergence and convergence processes in design.

In the last chapter, we translate these insights into implications for design educators and professionals. The contributions of this dissertation are both theoretical and practical. While the constructivist notion of framing has deepened our understanding of the design process, models for describing frames are absent in the literature. Such models enable us to concretely characterize and systematically analyze the process of framing. From a theoretical perspective,

3 Dual process theories model cognition as an interaction between two distinct processes.

this project aims to apply the specificity of cognitivist models of describing knowledge to the description of the problem frame. Through empirical studies, we apply these new lenses to offer insights into the design process.

Chapter 2 A Narrative and Network Approach for Representing Design Frames

In the past decades, design researchers have analyzed the design process from a variety of perspectives. One of the perspectives with an established history for analyzing the design process is that of framing. Schön (1983) introduced the notion of framing as the process of structuring the design situation by searching for relevant elements and conjecturing a set of relationships between them to construct a frame. In this sense, the design process is not only to generate ideas but also to construct problems from indeterminate situations.

Despite the emphasis on the role of framing in design research, very few studies have offered a formal characterization of the structure and content of frames. This description enables us to identify frames and trace their transformation over the course of the design process. In this chapter, two interlinked models are presented for representing design frames: narrative and network. The narrative model builds upon the storytelling perspective of design (Erickson, 1996; Lloyd, 2000; Parrish, 2006; Lloyd & Oak, 2018), however, a distinction is made between the concept of a story and a narrative. The story is the structure that designers construct to make sense and to externalize their understanding of the situation. The narrative is an overarching structure that connects these stories into a coherent, open-ended, and actionable problem. Within the narrative, designers can generate new stories to move towards a solution. On one hand, this model offers a framework for identifying frames and tracking their evolution during the design process. On the other hand, it enables connecting the storytelling model with Schön's model of reflective practice. Next, we discuss the network model presents stories as a series of interconnected concepts. Building upon Actor-Network Theory, these networks describe stories using four elements: actors, actions, affordances, and attributes.

Background

Donald Schön’s theory of reflective practice (1983) offered an alternative to the technical rationality perspective of design dominant in the 60s and 70s. Schön (1983) described the design as a conversation between the designer and the materials of the situation. The designer is in an interactive relationship with the situation: he acts upon the situation, allows the situation to *talk back* to him/her, and reflects on this backtalk which allows "him to see things in a new way to construct new meanings and intentions" (Schön, 1984, p. 132).

One of the main distinctions between the reflective practitioner and technical rationality perspective is their conceptions of the design problem and the designer’s approach to problem-solving. The technical rationality perspective - as presented by Herbert Simon (1973, p.181) - describes design problems as *ill-structured* problems that "lack definition in some respect". Solving an ill-structured problem starts with establishing some general constraints and specifications that originate from external sources or the designer’s long-term memory. For instance, architects start designing a house by considering external constraints (e.g. budget, codes) and related attributes that they select from memory (e.g. structural systems, materials) (Simon, 1973). Designers then decompose each attribute into their constituting components and each of these components can be further decomposed into subcomponents. For instance, the structural system of a house can be decomposed into walls, roofs, and foundation systems and a roof system can be decomposed into subcomponents such as a support system, roofing, sheathing, and utilities (Simon, 1977). At the appropriate moments during the design process, design alternatives are evoked from memory or other sources "in component-by-component fashion" (Simon, 1973, p. 190). Designers consider different design alternatives for each component and options that fit their purposes. For instance, the problem of a roof support system may be a choice between a truss system or a beam structure.

Simon takes a Cartesian inquiry approach to solving ill-structured problems (Bamford, 2002). Similar to a machine, a problem can be disassembled to its components, each component is altered or replaced by a new component and finally, they are reassembled to a solution. In the process of analysis, the problem is divided "into as many parts as possible, and as might be necessary for its adequate solution" (Descartes, 1850, p. 18). While designing a house is an ill-structured problem at large, problems of component design are well-structured (Figure 2.1). Design is, therefore, a matter of choosing different variables within the boundaries and constraints of the problem space (Simon, 1988).

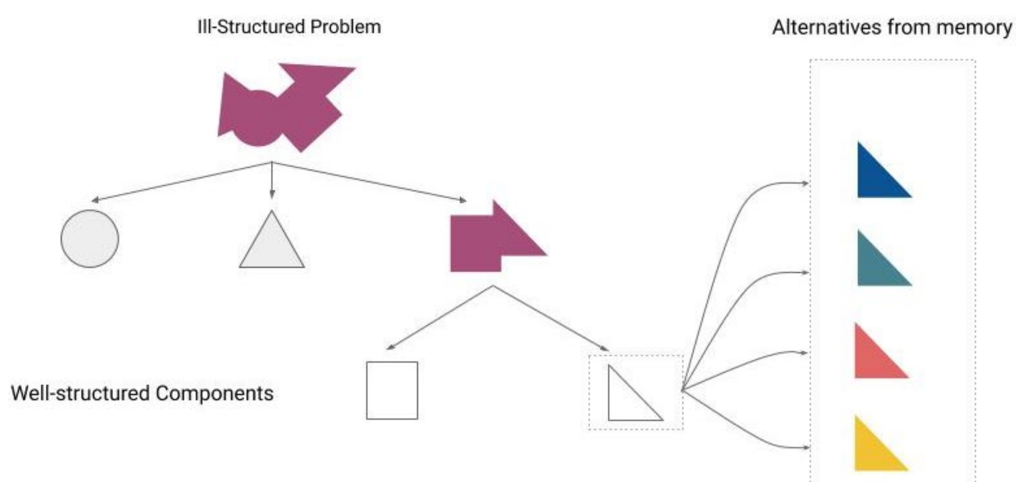

Figure 2.1. A decomposition perspective of the design process

In contrast to Simon’s emphasis on the *decomposition* of ill-structured problems, Hillier, Musgrove & O'Sullivan (1972) proposed a vision of design as a matter of conjecturing solutions and testing them against the constraints of the situation. Conjectures become possible by the knowledge of problem and solution types or *presetructures* that designers bring to the problem. Prestructures are highly stable patterns, generated and transmitted by cultures over long periods of time, which embody objects and relationships, and instructions and rules for using these objects. Prestructures enable designers to interpret the problem and project possible solutions, a process referred to as prestructuring. While the technical rationality perspective emphasizes the removal of a priori hypothesis from design, Hillier et al. (1972) place prestructures, as the essential units of design knowledge stored in the mental models of designers, at the core of the design process. Prestructures are models that can then be evoked in corresponding situations and the designer’s understanding of the situation is constructed by the prestructures that he holds. The design process is to use these mental representations of the world to recognize problems, and to test these hypothetical solutions against constraints imposed by the real world. If such a test fails, designers cognitively transform or elaborate the prestructure to continue the test cycle.

Hillier et al.’s approach to design knowledge resonates with the concepts developed in the information-processing tradition of cognitive science. The basic premise of this perspective is the idea that the brain encodes and stores information from past experiences into mental structures that are retained, and which can be later recalled based on the situation. These internal symbolic representations of the external reality (objects, relationships, procedure) are referred to as mental models (Johnson-Laird, 1983). Craik defines a mental model as a small-scale model of how the world works which enable us to understand the world and guide our action (Craik, 1943). Mental models reside in the working memory and function as reasoning mechanisms. Individuals invoke different mental models depending on the situation they are facing and may change their mental models over time.

The notion of the frame - as described by Minsky - refers to a similar structure (Minsky, 1974). Minsky defines a frame as a "data-structure for representing a stereotyped situation" whose characteristics may "be adapted to fit reality by changing details as necessary" (Minsky, 1974, p. 111). Minsky's notion of frames resonates with Hillier's notion of prestructures that unfold and adapt to the specific conditions of the situation. Minsky illustrates frame as a top-down tree-shaped structure for frames in which "top levels" of the frame are fixed "and represent things that are always true about the supposed situation" while the "low level" terminals/slots can be filled with new data from the specific situation (Minsky, 1974, p .1). Frames are interconnected structures that together shape frame-systems.

A similar notion of the frame was adopted by Klein, Moon, and Hoffman (2006) in their theory of sensemaking. The term sensemaking refers to the attempt for understanding "connections [among people, places, and events] in order to anticipate their trajectories and act effectively" (Klein et al., 2006, p. 71). Klein et al. describe a frame as a perspective or a viewpoint that people use to start making sense of the situation (Klein et al., 2006). Frames can be described in different forms including "stories, maps, organizational diagrams, or scripts" (Klein et al., 2006, p. 88). When encountering a new situation, an existing frame is used to make "a hypothesis about the connections among data" in order to explain what is going on (Klein et al., 2006, p. 88). If the data doesn't fit into the frame, the person elaborates the frame by "adding and filling slots, seeking and inferring data, discovering new data [and] relationships" or discarding the data that doesn’t fit the frame (Klein et al., 2006, p. 89). However, as the inconsistencies between the data and the fame accumulate, the person might question the quality of data or, alternatively, replace the frame with a new one that can fit the data (Klein et al., 2006).

The notions of frame and framing were adopted by Schön in his constructivist theory of design. Like Hillier, Schön emphasis the active role of the designer’s knowledge in *structuring* the design situation. Schön suggests that designers build their knowledge through active engagement with the material of the situation and by reflecting upon it (Schön, 1992). This knowledge is organized in "design worlds" that are constructed "through the shaping of materials" and "interlocking processes of perception, cognition, and notation" (Schön, 1988, p. 183). Design worlds are the structures holding this design knowledge that designers enter and inhabit to frame the situation. Design worlds contain "particular configurations of things, relations, and qualities" which direct attention to specific elements in a situation and establish order among these elements (Schön, 1988, p. 182). Designers use these design worlds to impose their vision on a situation by structuring "in it a version of a more or less familiar design world" (Schön, 1988, p. 183). In this sense, "the reality of a design situation" is constructed rather than discovered by a designer (Schön, 1992, p. 9). Schön (1988, p. 183) suggests a transactional relationship between the designer and design situations "in which a designer both transforms a design situation and enriches the repertoire of types available to him for further design".

This constructivist perspective is echoed in the work of Akrich who identifies design as a process of projecting and hypothesizing "about the entities that make up the world into which the [designed] object is to be inserted" (Akrich, 1992, p. 207). Design is a back and forth "between the world inscribed in the object and the world described by its displacement" (Akrich, 1992, p. 209). Designers construct the reality of the situation where their products are going to be used. Akrich suggests that this "vision of the world" is defined by a set of heterogeneous actors "with specific tastes, competences, motives, aspirations, political prejudices" that live in a world where "morality, technology, science, and the economy will evolve in particular ways" (Akrich, 1992, p. 208). These visions of the world are not static rules in the designers' minds projected into the world but dynamic systems of words and objects that designers constantly re-define through their interactions with the situation.

Notions of the design world (Schön, 1991) or vision of the world (Akrich, 1992) also share similarities with Goodman's constructivist notion of worlds and worldmaking. According to Goodman (1978), our knowledge of the world is generated and structured inter-subjectively into *world* versions: ways of interpreting and describing a reality that is organized in symbolic systems of words, shapes, objects, or sounds. In this constructivist perspective, knowledge is constructed through the interactions between the individuals and the environment (Kinsella, 2002). The mind is not a passive reflector of the outside world but an active creator of knowledge by giving order and meaning to reality.

What distinguishes Schön's theory of design is its focus on the framing, the process of shaping frames for understanding unique and novel situations. Schön offers a dynamic and situated model of the design knowledge that is being constantly transformed as a designer interacts with the environment. This dynamic understanding of the design world directed Schön's attention to the interactive relationship between the designer and the situation which he refers to as *reflective practice*. This is due to Schön's approach to design in which knowledge is constructed through the interaction between cognitive structures and the experiences of the environment. In this perspective, the designer engages in a conversation with the material of the situation: he acts upon the situation, allows the situation to 'talk back' to him, and reflects on the results of his action (Schön, 1984). Through this conversation between the design worlds and the design situation, the designer frames the situation: he sets the boundaries of the design situation, selects and names the elements that are relevant to his problem, and imposes a coherent structure to guide further moves (Schön, 1988). This process results in the formation of an understanding of the situation i.e. a frame (Figure 2.2) . A situated frame is not a predefined category but the result of an interaction between a designer and a specific situation (Van Hulst & Yanow, 2016). It is within this frame that a designer's action (design move) starts *moving* towards a solution. As Kolko puts it "a frame is an active prospect that both describes and perceptually changes a given situation" (Kolko, 2010, p. 1).

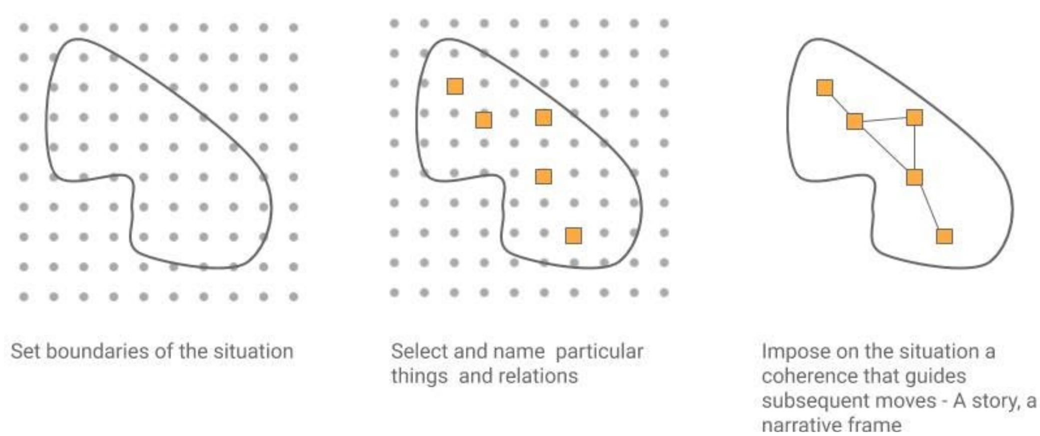

Figure 2.2. The reflective practice perspective of the design process

This interactive perspective suggests a reciprocal relationship between the problem and solution in which "designing triggers awareness of new criteria for design [and] problem-solving triggers problem setting" (Schön, 1988, p. 182). Similarly, Dorst and Cross (2001) suggest that during the design process the problem and solution spaces co-evolve. Their empirical study of the design process of nine experienced designers showed that to start the search for a solution, creative designers do not fix the problem space at the beginning of the design process (Dorst & Cross, 2001). In contrast, the design is a matter of evolving problem and solution spaces through the cyclic processes of analysis, synthesis, and evaluation (Dorst & Cross, 2001). Solutions proposed by designers constantly restructure the formulation of the design problems; and designers proceed to resolve the new problems (Dorst & Cross, 2001). As designers engage in this reflective interaction with the situation, they reflect on the frames they hold which can lead designers to see the situation in new ways - to reframe. At some point, a designer might find the existing frame to be obsolete and to replace it with a new frame or transform it to be compatible with the situation. Two consequences of taking a constructivist approach to designing are:

1. Frames and framing are at the core of the design process. The designer draws upon frames to make sense of the existing situation and to imagine new situations. These frames are not objective reflections of the outside world, but they are structures shaped through assigning meaning and order to the elements of the world.

2. Design frames are constantly being restructured as designers interact with the materials of the situation. Therefore, framing is a dynamic process that is shaped through the interactions between the design world and the design situation.

Framing and Reframing in Design

A growing body of research has emerged out of the constructivist approach to the study of the design process. Researchers have explored the potential of framing as a lens to analyze the design process. These studies often utilize protocol analysis, a method that relies on the analysis of verbal communications between designers during the design process. Design team members express their understanding of the design situation and discuss their ideas by engaging in a conversation with each other. Therefore, analyzing design conversations can open a window into the underlying cognitive and social processes of design.

Valkenburg and Dorst (1998) built upon Schön's theory of the reflective practitioner to offer a model for the analysis of the conversations of design teams. This model consists of four activities: the naming of the elements in the design situation, the framing of the problem, moving towards a solution, and reflection on moves and frames (Valkenburg & Dorst, 1998).

Stumpff and McDonnell (2002) introduced an argumentative/rhetorical approach to the study of framing. In this perspective, framing is a social process and frames are established through negotiations between designers. Through these negotiations, designers restructure or link elements of the situation that are already accepted by designers (associations based on the structure of reality) or link existing and new elements of the design situation (association to establish the structure of reality). Designers resolve the conflict between different frames by shifting their conceptual models and making a creative change in their perception of reality (dissociation) (Stumpf & McDonnell, 2002).

Hey et al. (2007) adopted this argumentative approach to framing in teams. Design starts with setting pseudo-frames or the "initial understanding of the design situation". However, as these pseudo-frames become more explicit, they reveal their differences. These conflicts between frames are resolved through a process of negotiation, argumentation, and persuasion which results in the construction of common frames. Reflection and negotiation of frames can result in changing design actions (or moves) or reframing of the situation. The authors' model of framing accommodates frame negotiation as an integral part of the design process in teams (Hey et al., 2007).

To explain reframing and the adoption of new frames during the design process, Stompff et al. introduced the concept of surprise into the Valkenburg-Dorst model (Stompff et al., 2016). They proposed an iterative model of the design process during which designers develop a frame of the existing situations and move towards a solution using this frame. As they reflect upon these moves and frames, an unexpected situation might emerge either because of a mismatch between the frame and situation or presentation of new opportunities in the situation. Faced with this situation, designers might change their moves or introduce a new frame.

The Gap

While framing has been a central topic in the study of the design process, less work has been done building frameworks for formally describing the structure of frames. Therefore, attempts for mapping frames and investigating the transformation of their structure during the design process have remained rather limited. Making frames explicit can help us to improve the design process in two ways. First, the framing of the design problem is central to creativity in design. Previous studies show that a shift in the frame is the key to creating innovative solutions

(Verganti & Norman, 2014; Dorst, 2011). It is through reframing that a designer sees a situation in new ways and imagines solutions that couldn't be achieved in the old framework. However, frames are embedded within design material and conversations and can remain hidden from the designer's conscious perspective. Making frames explicit, and understanding how they enter the design space, will open a new way for designers to reimagine their understanding of the situation and explore new design environments.

Second, frames are strategic tools in the design process that can create a shared vision among different members of the design team. As Kolko (2012) points out, the increasing complexity of design problems, the growing interdisciplinarity of design teams, and the invisibility of design artifacts have raised the importance of making the design process more explicit. Making design frames more explicit can improve the shared understanding of the complex and unique problems of design.

To build formal ways of mapping the generation and transformation of frames during the design process, we build upon two existing approaches in cognitive science and artificial intelligence to represent knowledge: narratives and networks. This chapter starts with an overview of the existing narrative approaches to the design process followed by a description of our narrative model for representing design frames. Next, network approaches for representing knowledge will be discussed. Finally, we'll present a network approach for presenting design frames. This chapter provides a general framework for these approaches and a more detailed description of the methods will be offered in the following chapters.

Narrative Representation of Frames

Narrative representation of knowledge has been adopted by researchers in both cognitivist and constructivist traditions. Minsky (2007, p. 281) suggests that stories and scripts are the "most familiar ways to represent an incident" which "depicts a sequence of events in time". The story is an episodic structure for knowledge which represents a series of events in a sequential format. Humans start developing these stories from an early age which guides their understanding of the events, how they should respond to these events and the outcome of those actions**.** Brunner (1991) proposed that human experience and memory are mainly organized as narratives that "represent a version of reality" (p.4). Stories influence human experience by structuring the way we think about how things have been in the past and how they might be in the future. Knowledge and memory are constructed by stories from personal or social experience which in turn allows a person to interpret new experiences (Abelson & Schank, 1977).

Narratives and stories have been utilized as a lens to study the design process (Akrich, 1992; Rein & Schön, 1996; Lloyd, 2000; Lloyd & Oak, 2018). The storytelling perspective suggests that the design process in general and frames, in particular, are structured in a story-like format. We make sense of the existing situation and imagine future ones through narrative structures. At its core, this approach conceives design as the process of telling stories and connecting the existing reality of the situation (what is going on) with the imagined possibilities for the future (what can be).

Akrich (1992) proposed that design involves creating a script or scenario that describes the actors and their expected interactions with the design object in the world conceived by the designer. A scenario narrates a series of events in which actors interact in certain ways and it is expected that characteristics of the design object elicit certain interactions from the actors. In the storytelling model proposed by Lloyd and Oak (2018) designing is to create, negotiate and connect two sets of stories: *past particulars* and *imagined particulars*. While the former structures existing experiences and behaviors, the latter "place(s) specific actors, objects, and relations into an imagined context" (Lloyd & Oak, 2018, p. 109). By taking a constructivist approach, the storytelling perspective conceives framing as the process of co-constructing "verbal stories" which allow designers to discuss and negotiate "opposing values without the need to resolve them" (Lloyd & Oak, 2018, p. 94).

Rein and Schön (1996, p. 89) suggest that frames are "narratives that guide both analysis and action in practiced situations". These narratives are at the same time framing devices that direct the way one thinks about an issue and "reasoning devices which shape what should be done about the issue" (Rein and Schön, 1996, p. 89). In this sense, Schön and Rein suggest that framing is, in fact, a work of storytelling in which designers bring seemingly unrelated elements together. Naming and selecting is followed by storytelling: connecting elements to shape a coherent narrative of the situation. Such situational stories help designers to structure and communicate their understanding of a problem. Stories frame and communicate to others "what has been going on [and] what needs to be done” (Van Hulst & Yanow, 2016, p. 100). When compared with the reflective practitioner framework, the first process resembles *naming* (elements of the situation) and the latter shares similarities with *moving* (towards the solution).

We propose that a design frame can be regarded as a narrative that connects the stories constructed from the situation and allows the designer to generate solutions. Stories represent the *who, where, when and how* of the events of a situation. They recognize actors and establish a coherent set of connections between them through actions and associations. Designers might generate several stories from a situation before initiating a narrative. Each of these stories might represent a different situation with a different set of actors and actions. Narratives connect these stories to create an overarching structure that presents an actionable problem.

As it can be noticed, at the core of this model is a distinction between stories and narratives in design. A narrative is different from a story in at least two ways. First, a narrative is a system of interconnected stories "that work together" (Halverson, 2011). A well-known example of such a narrative is global warming which simply states the temperature of the earth is rising due to human activities. Every day multiple stories are being published by news organizations or academic institutions which get connected to the narrative of global warming ranging from the wildfires in California to the melting of an iceberg threatening a small village in Greenland. A narrative creates a structure that connects all these seemingly disconnected stories to shape an overarching message. Narratives are at the same time a basis for the interpretation of the situation and a source of action.

The second distinction is that stories are closed while narratives are open-ended (Hagel, 2016). Carmen points out that the open-ended nature of the narrative is the result of their systemness. The narrative provides a framework in which "new stories can always develop and relate to other stories in the system" (Carmen, 2013). Therefore, the narrative presents an ongoing matter which calls for participation and brings forth unresolved situations in which the audience can act. Narratives offer a structure for interpreting the situation and also present a problem that calls for action and resolution.

By making a distinction between stories and narratives, we can draw a direct line between the narrative model and the theory of reflective practice. Valkenburg and Dorst (1998) formulate the steps involved in reflective practice as the following: "*naming* the relevant factors in the situation, *framing* a problem in a certain way, making moves toward a solution and, evaluating those moves". With the narrative model in mind, these steps can be reinterpreted as follows: 1. Naming: interpreting the situation through the construction of stories; 2. Framing: creating an overarching narrative frame based on these stories; 3. Moving: creating stories to imagine a solution within these narrative frames.

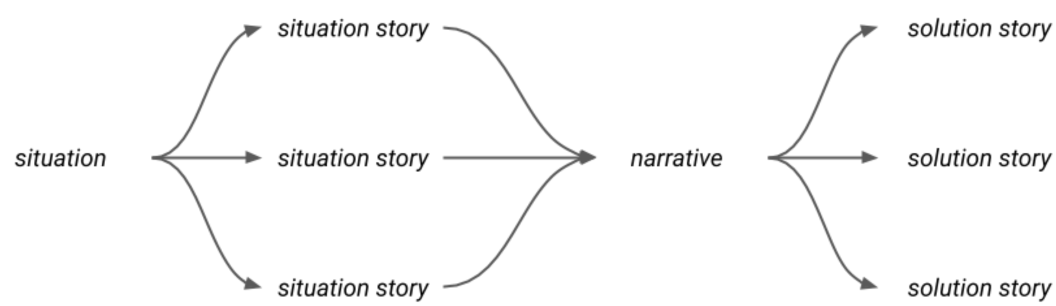

Figure 2.3. A Narrative model of the design process

The fourth element of Schön’s model (reflection) is present in all stages of the design process as designers constantly reflect on the stories and narratives they construct during the design process. It should be noted that the relationship between stories and narratives is reciprocal. While narratives structure stories they also act as an attractor for new stories that can reinforce or challenge them. New moves will respond to the narrative through reinforcing or challenging. Designers constantly move between narratives to create new stories or modify the existing ones.

This model situates the narrative at the core of the design process. The distinction between narrative and story creates a hierarchical relationship in the analysis of the design process. Narratives are located at the top level of this hierarchy, and stories are connected to these narratives. The narrative becomes the structural unit for describing frames that brings dispersed stories into a coherent and meaningful structure. We can use the following criteria for extracting frames in the design process: frames are narrative structures which present the problem within a situation. Designers constantly elaborate and modify narratives by adding new stories or removing the existing ones. The narrative model allows us to identify frames and follow their evolution during the design process. These elements are constantly being negotiated, augmented, and revised through the interactions between the designers. Similar to narratives, stories are dynamic, and they evolve as designers reflect upon their internal coherence, think about new relevant situations, and come up with new solutions.

Network Representation of Frames

A second approach for representing knowledge is the semantic network. While a story organizes knowledge in a temporal structure, semantic network arranges knowledge as concepts and their connections. The network is a generic structure that can accept any entities as nodes. While these characteristics of networks make them capable of showing a variety of structures but at the same time networks don't guide us for the kind of elements that we should look for. Therefore, to define a semantic network, we need to define what is considered a concept. The question is what elements should be extracted to best represent the design world as constructed by designers?

A theoretical approach that provides a framework for connecting the narrative and network representation of design is the Actor-Network-Theory. As a conceptual framework, Actor-Network Theory offers useful concepts for describing the design world and the role that artifacts play in mediating action (Latour, 2005). While other theoretical frameworks have discussed similar ideas, Actor-Network Theory offers a synthesis to explain the structure and dynamics of socio-technical systems (Latour, 1990; Akrich, 1992; Yaneva, 2009). To build this taxonomy, we adopted four concepts from Actor-Network Theory: actors, actions, affordances, and attributes.

Actor-Network Theory situates scripts or scenarios at the core of the design activity. Animated by the actions of an organized and connected collective of human and non-human actors (Callon, 2004), scripts illustrate how designers imagine the events in the world to unfold given their object of design (Akrich, 1992). Design is the process of creating a script or scenario and inscribing it in "the technical content of the new object" (Akrich, 1992, p. 208). Design stories describe situations that involve interaction between human and non-human elements. Following the actor-network theory, we refer to the elements that carry agency in the situation as actors. While the term actor is often reserved for human characters in a story, actor-network theory proposes that objects and environments are not merely tools external to the human subject. In contrast, they have an active role in shaping the processes that are being studied. Therefore, human subjects and non-human objects are situated within a broader ecosystem connected to other objects and subjects, which together shape a socio-technical system. The script is actualized through the actions of a network of human and non-human actors. The agency of actions is, therefore, distributed within this network. When used for non-humans, the agency doesn't refer to the capacity for intentional action but to how the "the material world pushes back on people because of its physical structure and design" (Latour, 1992). The material structure of the environment enables different modes of action, reconfigures the human agency, and mediates actions (Callon, 2004).

This active role of environment in shaping actions can be traced back to the work of ecological psychologist James Gibson who asserted that actions must be conceptualized within the "dynamic coupling between the animal and its environment" (Hutchins, 2010, p. 705). He defines affordance as what an environment "offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 1979, p. 56). Affordance is not an inherent physical quality of the environment nor a mere subjective perception. Instead, it's a hybrid concept that offers an alternative to the subject-object dualities and suggests a complementary relationship between humans and the environment (Gibson, 1979). Similarly, in the Actor-Network Theory, the concept of promission has been used to refer to what an artifact allows (permission) and what it suggests (promise) (Callon, 2004). Affordance or promission is necessary to action since "no unmediated action is possible" (Latour, 1994). Affordance is not an inherent physical quality of the environment neither a mere subjective perception but a hybrid concept that offers an alternative to the subject-object dualities and suggests a complementary relationship between the animal and the environment (Gibson, 1979). Affordances of an environment are specific and relational.

Affordances of an environment enable actors to perform specific actions and specifies its active role in shaping actions. Finally, actors have specific attributes that enable them to offer affordances to other actors. The scenario or script defines actors (human and non-human) that act in specific ways or make the actions of other actors possible through the affordances defined by their attributes (Yaneva, 2009). A person (actor) moving up (action) a ladder (actor) is made possible by the affordance (climbability) of the ladder, which is actualized by the width, material strength, and height (attributes) of the ladder's steps. The semantic space can be presented as a network of words representing the elements of design stories (actors and their actions, affordances, and attributes) and their relations.

In summary, our framework will use these four main elements to describe the design situation as imagined by the designers:

1. Actors: These are entities named by designers in the situation. Following the definition of an actor in Actor-Network theory, no distinction is made between human or non-human actors.

2. Attributes: These are visual, physical, or categorical properties of an actor. These properties can be described independently from other actors.

3. Affordance: The concept of affordance is adopted from ecological psychology and specifically the work of Gibson. For Gibson, affordances are the action possibilities offered by an environment to a human. It is important to note that affordance is defined relative to the actor and environments; artifacts offer different affordances to different actors.

4. Actions: These are what an actor performs using the affordances of other actors. Actions connect different actors and shape the network. Without actions, actors are merely a

collection of possibilities. A chair with a high "sit-ability" affordance and a tired person connect when the person performs the act of sitting.

Discussion

This chapter introduced a narrative model for representing design frames. This model is based on the idea that designers discuss their ideas using stories and those stories can be analyzed on two different levels. Our model expands the storytelling model by adding two levels of analysis. The first level of analysis is based on the notion that stories are not isolated components but connected to each other through underlying themes. Therefore, the design process can be studied in terms of these themes that connect stories into one or multiple overarching structures. We refer to these overarching structures as narratives.

Second, stories can be broken down to their constituting elements (i.e. actors, attributes) and their interactions. Designers constantly adding new elements to these stories or modify existing ones. Stories can be analyzed on the level of these constituting elements and their interactions. Designers use new words to describe these new stories or story elements of the situation. In our approach, no limitation is set on the connections between entities, and all entities can potentially connect.

Stories are structured around narratives that connect them and bring coherence to their structure. These narratives describe an understanding of the problem constructed through the interactions between the designers and the situation. On the other hand, stories can be broken down to their constituent elements. We propose that stories are made from actors, actions, affordances, and attributes.

Chapter 3 Managing Frame Multiplicity in the Design Process

Design starts with the structuring of the ambiguous and complex situation to construct a problem. Schön (1983) uses the term *framing* to refer to this process. Framing involves determining the boundaries of a situation, naming its relevant elements and structuring them into a coherent problem. The result of this process is a *frame*, an understanding of the situation which guides the actions of the designer and allows them to look for a solution in a structured and purposeful environment.

Framing is not a linear process that results in the generation of a single frame (Dorst & Cross, 2001). Instead, designers construct multiple frames especially during the ideation phase of the design process before arriving at a final frame. Design is a multidimensional process in which designers "think along parallel lines [to] deliberately maintain a sense of ambiguity and uncertainty" (Lawson & Dorst, 2013, p. 60). Similar to a painter or a cinematographer who walks back and forth between viewpoints to find the right frame, a designer moves between frames to evaluate their correspondence to the situation and explore their potential for solving a problem. Designers shift their focus of attention to different elements in a situation to explore it from different perspectives.

Hokanson and Nyboer (2018, p.14) point out that the flexibility of thought in the design process is "in response to the complexity of the design problems" in which "the full parameters of the challenge are not known”. By generating multiple frames during the ideation process, designers create potential environments for generating ideas. However, this potential is not released until these frames are explored to create ideas for resolving the issues of the problematic situation. Therefore, designers often strike a balance between generating new frames and exploring them in the process of creating ideas.

Frames are not parts of a larger function but parallel understandings of the situation. Multiple frames can co-exist within a design process and designers can switch between frames without necessarily replacing one with the other. If managed effectively, the multiplicity of frames allows the designer to look at the problem from a variety of perspectives before committing to a direction. The existing research has established the importance of framing in the design process. The ability to frame the design situation in new ways has been found to be a key characteristic of creative designers (Beckman & Barry, 2007; Paton & Dorst, 2011; Norman & Verganti, 2014; Dorst, 2015). However, less attention has been paid to the strategies utilized by designers to manage the multiplicity of frames in the design process. The purpose of this chapter is to study these strategies by studying the temporal distribution patterns of frame generation and exploration activities over the course of the design process. We specifically focus on the ideation phase of the design process because designers are still not committed to any frames or ideas and are open to exploring different viewpoints. The following research questions guided the research:

1. What are the different strategies utilized by designers to generate and explore frames in the design process?

2. What strategies are associated with design teams that generate more frames and ideas?

Research Approach

To answer these questions, we present a protocol analysis (Ericsson & Simon, 1993) of 16 ideation sessions. Protocol analysis is a popular method for investigating the design process through the analysis of verbal communications between designers in controlled design sessions. Protocol analysis conceives the design process as a sequence of events unfolding over time to analyze the temporal dimensions of the design process. Ideation sessions are often short-term design activities. However, they are suitable for studying the framing process since they contain both elements of the problem-solving process: constructing problems or frames and generating ideas within them.

In the next section, we will present a model for analyzing frame generation and exploration strategies in design using the narrative approach to frames introduced in chapter 2. This perspective treats frames as narrative structures that offer a diagnosis of the problematic situation and a vision towards the solution. Rein and Schön (1996) refer to these structures which are concerned with the why of the situation as frame-narrative. Next, we will describe our data collection and analysis methods, followed by the results. Two strategies for frame generation (concentrated and diffused) and exploration (parallel and serial) were identified. The results show that most design teams used a mix of both strategies. Also, design teams who used the parallel frame development strategy generated a higher number of frames and ideas.

Method

The frame is the environment and the context in which design activities take place. The design process can be modeled as a series of moves that are situated within frames (Valkenburg

& Dorst, 1998). Designers also can shift between frames to change their perspective. In their model, Valkenburg and Dorst visualize "frames as a box in which other activities occur" (Valkenburg & Dorst, 1998, p.255). Designers generate frames and use them to further advance the design process. It should be noted that frames are not discussed in this chapter as subproblems or partial solutions but different viable understandings of the situation which can run in parallel to each other. The design process can be modeled as a series of moves progressing over time within these frames.

We conceive design as the interaction between two major processes: generation (construction of new frames) and exploration (interpretation and development of frames to explore their potential for creating solutions). This bimodal conception of the design process can also be seen in cognitive models such as geneplore (Finke, Ward & Smith, 1992) and divergence-convergence model (Liu, Chakrabarti & Bligh, 2003). Frame generation sets the narrative for the following moves and allows designers to respond to it. As mentioned earlier, designers move back and forth between these frames to shift their perspective of the situation. In this study, we look at the patterns of frame generation and exploration by categorizing design moves into three events (figure 3.1):

1. Frame-Generation: Design moves in which designers define a new frame.
2. Frame-Exploration: Design moves situated within a frame after the initial frame generation move.

3. Frame-Shift: Design moves in which frame exploration shifts between two already-defined frame.

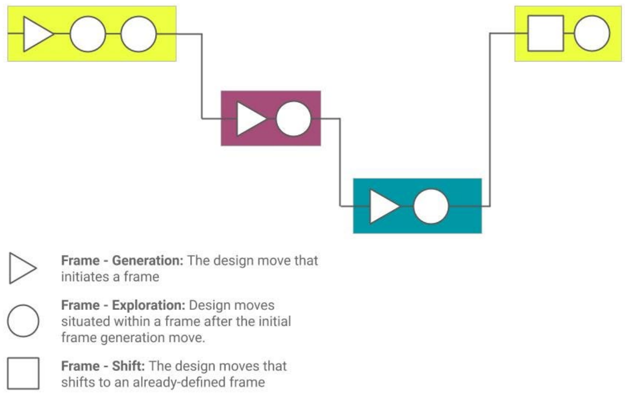

Figure 3.1. Frame generation and exploration model (Adopted and modified from Valkenburg & Dorst (1998)

Identifying these three events for every ideation session allows us to answer questions such as:

1. How many and when in the process are frames were generated?
2. How many moves have been dedicated to exploring each frame?
3. How many times have designers shifted between frames?

Answering such questions then allows the identification of strategies utilized by designers to manage frames. The approach we take in this chapter builds upon the breadth/depth-first model, a well-known model in problem-solving literature which similarly approaches design exploration from a temporal perspective. This model is rooted in the problem decomposition perspective of the design process (Simon, 1973) in which ill-structured problems can be solved by being decomposed into small and well-defined problems (Simon, 1973) that are "more transparent and less-complex" and "can be solved separately" (Liikkanen, 2009, p. 40). Problem decomposition is an inherently hierarchical conception of the design process in which each problem needs to be decomposed into smaller and smaller components until it can be solved. Designers decompose the main function into solution types, subfunctions, and principles (Liikkanen, 2009).

Ball and Ormerod (1995) proposed that designers utilize two strategies to decompose a problem: a depth-first strategy in which one sub-goal is developed in detail before moving to the next one; and a breadth-first strategy in which each sub-goal is developed until a level of detail is achieved before getting to the next level of detail. This model conceives of the design space as a tree-like structure. Design steps can explore branches of this tree (problem sub-components) one by one (i.e. depth-first) or simultaneously (i.e. breadth-first).

While this study is mainly concerned with frame construction, and not the level of design development, the breadth-first/depth-first model of problem decomposition provides a useful framework for modeling frame exploration strategies. Frame generation and exploration can be similarly modeled as a series of events unfolding over time. We take the temporal density of these events as a measure for identifying frame generation strategies. Based on the concentration of their occurrence over time, these events can be categorized as *concentrated* (multiple frames are generated within a short time span) or *diffused* (frames are generated over an extended period of time). In the concentrated approach, designers focus on the frame generation and then utilize the rest of their time to explore these narrative-frames. In the diffused approach, frame generation events are distanced by periods of frame exploration.

We defined the frame exploration strategies based on the density of frame-shifts. In a *parallel exploration* strategy, designers constantly move back and forth between different frames. In a *serial exploration,* designers focus on a frame and develop it before moving to the next frame. During this focus period, designers might elaborate or challenge the frame and explore its potential for generating solutions. While in a *serial* frame exploration, designers rarely switch between frames they have generated, a *parallel* exploration is marked by the constant switch between frames. Designers start exploring a frame and before reaching its full potential switch to a new one. These shifts allow the designers to expand their understanding of the situation and to look at it from different perspectives.

When designers revisit a frame, they bring with them a new perspective which enriches their understanding of the other frame. The ideas and situations constructed in the old frame guide the ideation in the new frame, and new elements and ideas allow the designers to look at the problem in new ways. In this sense, switching between frames blends the boundaries between frames and connects their structure.

Model

To identify the strategies used in each session we need a formal definition of each strategy. The frame generation strategies differ based on the density of the frame generation moves. While in the concentrated strategy frames are generated in close proximity, in the diffused pattern considerable gaps exist between the frame generation events. To formally define each strategy, a threshold value (T) should be set to differentiate between the two patterns. Frame generation pattern$G$ consists of frame generation moves $\{g_i, g_j, \ldots\}$. Consider g_y to be the frame generation move within G with the closest index value to move g_x. G is *concentrated* if:

$$|x - y| < T$$

G is a *diffused* frame generation pattern if for all frame generation moves within G (g_x) and their closest frame generation move (g_y):

$$|x - y| \geq T$$

Similar to the definition of the exploration strategy we need to define a threshold value for the density of frame-shift moves. Frame exploration pattern F consists of frame-shift moves $\{f_i, f_j, \ldots\}$. Consider f_y to be the frame generation move within F with the closest index value to move f_x. F is *parallel* if:

$$|x - y| < T$$

F is a *serial* frame generation pattern if for all frame generation moves within F (f_x) and their closest frame generation move (f_y):

$$|x - y| \geq T$$

In the next section, we will describe the empirical study of ideation sessions of graduate students in design where we used this model in our method of analysis.

Empirical Study

In the following section, the process of data collection and analysis is presented. 32 graduate students from four design disciplines (architecture, human-computer interaction, integrative design, and urban design) were recruited through an open online call for participation at a Midwestern university. Recruited students were pursuing a master's (n=32) or a Ph.D. degree in one of the above-mentioned fields and had some design experience in academic or professional settings. Each participant was paired with another participant from a different disciplinary background. Participants were selected from different disciplines to diversify the perspectives and consequently frames generated in the design process. Prior to the session, participants signed a consent form to be voice recorded. All participants received a $20 incentive after completing the task

Study Design

Initially, two different design briefs were generated and tested with a pilot group. These briefs were evaluated based on their potential for being interpreted in different ways and generating multiple frames. We selected the brief which showed a higher capacity for being approached from multiple perspectives and creating different frames.

All participants received the same design brief and instructions at the beginning of the ideation session. The brief described a problem involving student safety at the university where participants were recruited. Since the context of the problem was familiar to students, they could draw on their personal experience and prior knowledge of the situation. To enhance options for ideation, the brief clarifies that solutions are not limited in terms of technology or scope. A detailed description of the task is illustrated in appendix 1. After reading the brief, participants were given 45 minutes to collaboratively work on the problem and generate ideas. Each design session was observed and voice-recorded by the principal investigator. Students were not guided by the researcher so that the ideation session could take its own course of action. Participants were also each given a sketchpad to draw and write-down their ideas. At the end of each session, the researcher collected the sketchpad; and participants were also asked to list the ideas they had generated.

Data Analysis Approach

The first step of the analysis was to divide the transcript into smaller segments. Each design session was divided into operation-steps known as moves. Goldschmidt (1995, p. 89) defines a design move as “a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move”. Moves externalize mental processes used during the design process. The assumption was that each move is either situated within a frame or is geared towards building a frame. Design moves situated within frames were coded with the associated frames constructed by designers during the study.

Next, frames constructed in each session were identified, and each move was coded with the associated frame. A challenge for analyzing our data is the difficulty of eliciting frame-narratives without interfering in the design process. Previous studies have used methods such as active engagement which asks designers to declare their constructed problems before starting the design process. However, these approaches disrupt the design process flow in which designers generate and explore frames not in one-burst but in an interactive process (Dorst & Cross, 2001).

To address this challenge we took a collaborative, iterative and inductive approach to coding. We followed the inductive approach of grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1990) which allows “the patterns, themes, and categories of analysis” to emerge out of data “rather than being imposed on them prior to data collection and analysis” (Patton, 1980, p.

306). Analysis codes were extracted and refined through an iterative process. We utilized Rein and Schön's definition of the frame-narratives to guide coders in their search for these codes. Rein and Schön (1996, p. 89) define frame-narratives as "diagnostic/prescriptive stories that tell, within a given issue terrain, what needs fixing and how it might be fixed". This definition draws a distinction between the diagnostic nature of frame-narratives and the descriptive nature of stories. While both frame-narratives and stories are animated by actors and actions, frame-narratives provide an explanation for the situation while stories describe the situation. Frame-narrative is not an anecdote but a diagnosis that guides towards action. While frame-narratives can be substantiated and reinforced with stories, this is not a necessary condition when analyzing the design protocol. Therefore, a frame-narrative can emerge before stories and the following moves tell stories that either support, challenge, or augment this frame-narrative. Table 3.1 illustrates the differences between stories and frame-narratives.

Story	Specific	Descriptive	close-ended
Frame-narrative	Generic	Diagnostic	open-ended

Table 3.1. A comparison of stories and frame-narratives

The following move extracted from one of the design sessions only offers a general statement regarding the situation:

> *I never saw any of these being used and I know they existed but I didn't even know how they were used. There's only one of them that I know where it is.*

While this statement offers a description of the existing situation based on the designer's personal experience, it doesn't identify the cause of the problematic situation. In this sense, it doesn't offer any basis for action. Now, consider the following excerpt from one of the same design sessions that offers a specific diagnosis of the situation (the appearance of blue light phones doesn't catch student's attention and therefore they go unnoticed) and a path for resolving the issue (changing the appearance of the blue light phones):

> *Why most students know the system but can't locate or find it when they need [it or] when they're in an emergency? It probably has to do with the* ***color*** *itself.* ***The blue color is not striking at all. It is not something that catches your attention as you walk past it*** *... um ... that doesn't make you notice because [it is] against the backdrop of the green.*

In contrast with the first excerpt, this is an open-ended statement that has a clear implication for action. Coders analyzed the design moves in each session using this definition and the resulting frame-narratives were negotiated and consolidated through a collaborative-coding process. This approach allowed code the moves in the design process and to track how they have been used during the design process. The principal investigator and a second coder were familiarized with this definition of narratives before starting the coding process and they reached an agreement on the notion of frame-narratives.

In summary, the process of coding was conducted as follows:

1. Each design session was broken down into its segment i.e. design moves.
2. To identify frames in each design session, all design moves, starting from design move 1, were evaluated. The first move which satisfied the frame-narrative criteria (presenting an open-ended narrative that presents an actionable problem regarding the situation) was added to the frame repository.
3. When all frame-narratives had been extracted, they were compared against each other for each session and similar narratives were combined to reduce redundancies.
4. Next, these frame-narratives were used as codes and assigned to design moves. All design moves were evaluated based on their correspondence to the frames in the frame repository. If the move corresponded to any of these frames, it is coded under that frame. Otherwise, the move is coded as none.

When coding was complete, each design move was either coded with one of the frame-narratives extracted during the first step or was coded as 'none' if it did not fit into any of the narratives. The results of this analysis allow us to build a profile of the design session which shows the narratives used during different stages of design. Using this profile, the number of moves was identified for each frame that was initiated; and the number of times designers switched between different frames was recorded.

Results

Sixteen design sessions were analyzed using the coding scheme. After completing the coding process, the sequence of frames was mapped used during a design session. An example of such a frame sequence is visualized in figure 3.2. All diagrams are documented in Appendix 2.

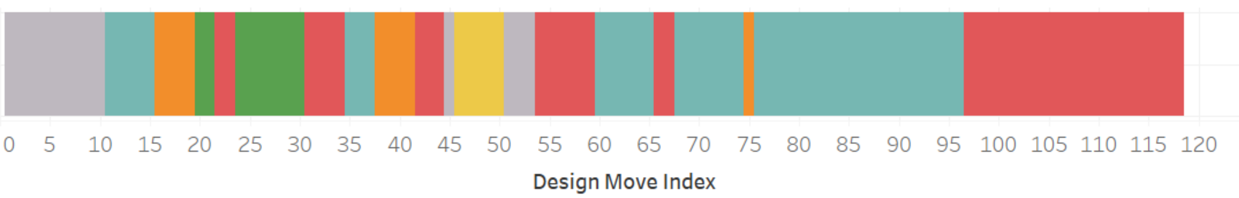

Figure 3.2. Design frames used in each design move

In this diagram, the color gray represents the moves that are coded as *none* and other colors represent a unique frame. This diagram makes it possible to extract different information about frame generation and exploration during each design session. First, the number of frames in each design session is identified; then each move within a frame has been generated. The number of times that designers have shifted between frames and the move index of these shifts are also identified.

Frame Generation Patterns

We start our analysis by looking at the temporal patterns of the frame generation. Figure 3.3 shows the number of frames identified in each session (min = 2, max = 7).

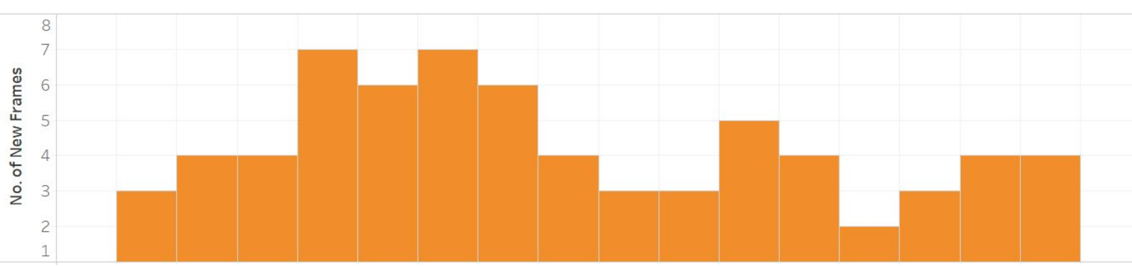

Figure 3.3. Number of frames generated in each session

Figure 3.4. shows the percentage of frames generated during different periods of the design process. Since design sessions have a different number of moves, the total number of moves in each session was divided into 10 equal segments. This allowed us to aggregate the frame generation events not based on the move index but based on the time segments. The total percentage of new frames generated in each segment was calculated.

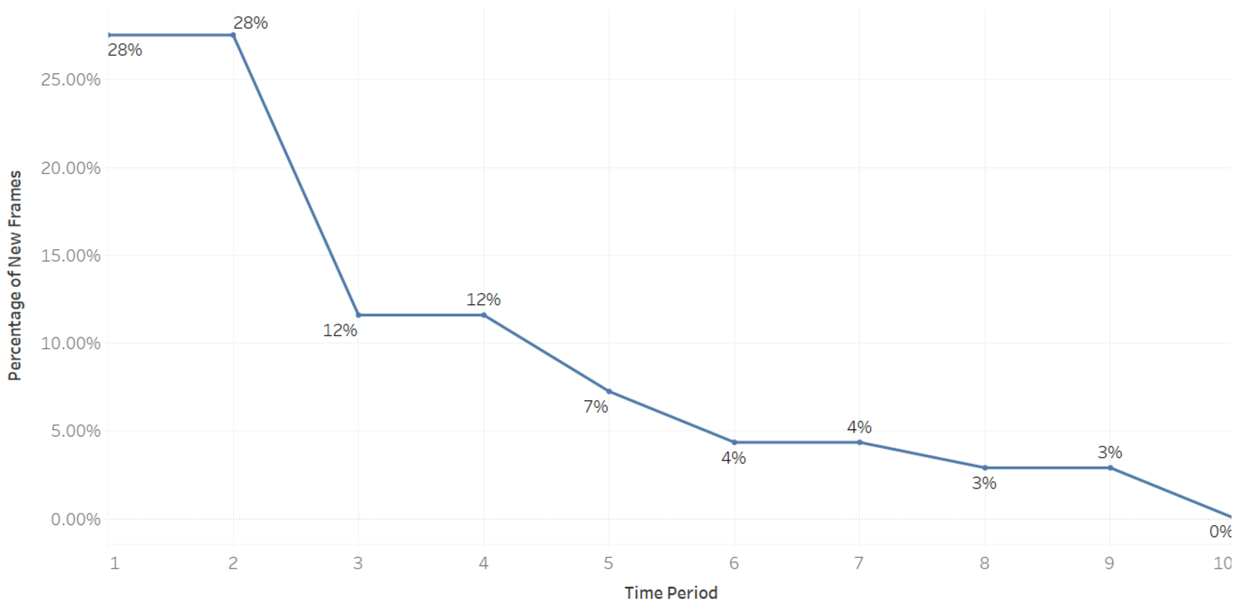

Figure 3.4. Number of frames generated over time

As figure 3.4. shows, 56% of the new frames were generated in the first two segments of the design process. After this initial phase of frame generation, the number of new frames generated decreases abruptly. The percentage of new frames generated during the third period is less than half of the second segment. The number of newly generated frames decreases again after the first half of the design session and only 14% of the ideas are generated during the second half of the session.

This pattern indicates that most frames are generated early in the ideation session. Instead of studying the brief and going through the process of naming to build situation stories, designers offer multiple initial frames. While at this point frames lack particular details and are discussed with few moves, they act as attractors for the generation and structuring of new stories and present an actionable narrative. This is similar to what Hey et al. (2007) refer to as pseudo-frames. These frames provide an explanation of the situation based on the designer's initial reactions to the issues raised in the brief. These initial frames are then used by designers to further explore the situation or generate solutions. These initial hypotheses allow designers to make sense and negotiate the situation before fully exploring the potentials of each frame.

In 13 out of 16 sessions (81%), designers generated at least one frame in the first segment and all groups generated a frame before reaching the third segment (figure 3.5). While designers generate most frames at the beginning of the design process, they continue generating frames after this initial phase. In half of the design sessions, at least one frame was generated during the second half of the design process. These frames often emerge after an initial process of exploration.

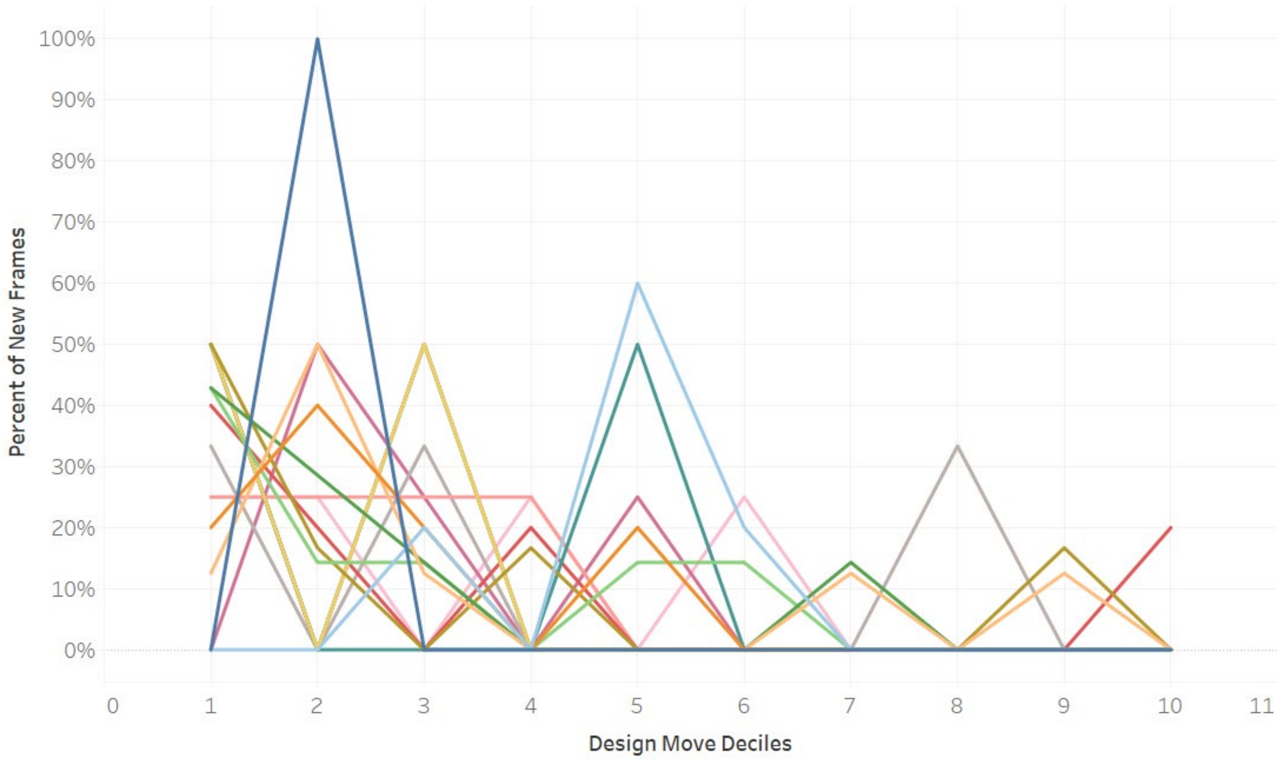

Figure 3.5. Number of frames generated over time per team

Frame Shift Patterns

Using the diagrams, we can also extract the move indexes in which designers have switched from one frame to another. Each frame shift marks the designers switching between two already established frames and does not include the emergence of new frames. Figure 3.6. shows the number of frame-shifts over the time period that has emerged during the design process. On average designers have switched 9.43 times between different frames (min=2, max = 24). The number of frame-shifts gradually increases during ideation and drops towards the end of the process (figure 3.6).

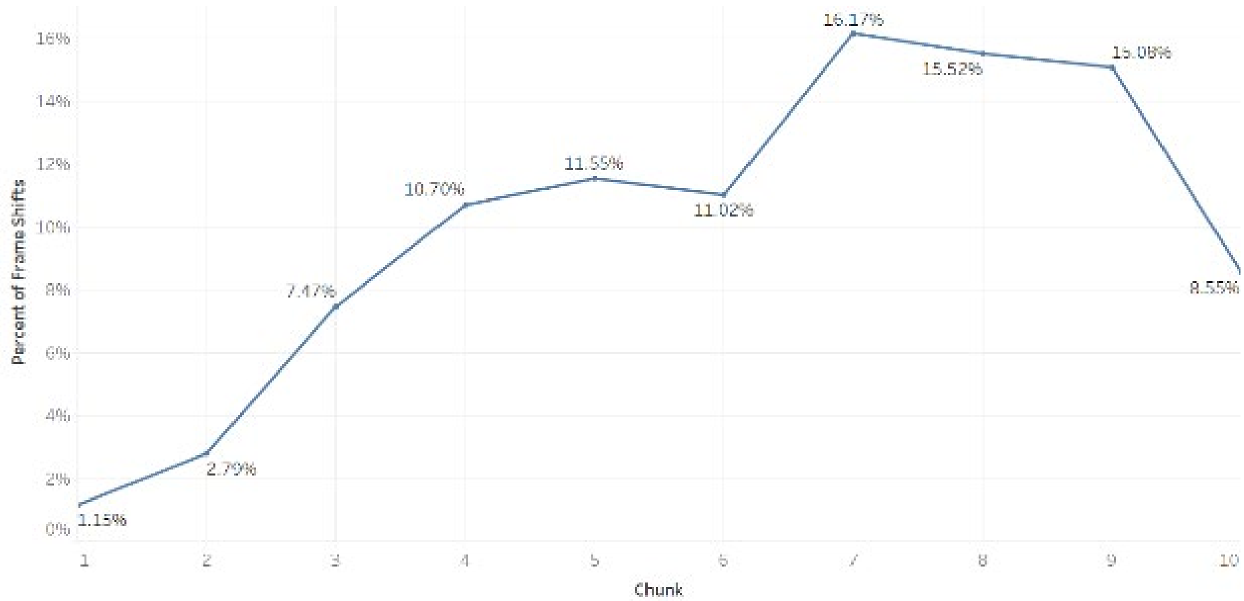

Figure 3.6. Percentage of frame-shifts during the design process

Frame Generation and Exploration Strategies

To detect the frame generation strategies, we look at the time distance between frame generation moves. The temporal distribution of frame generation moves (figures 3.4 and 3.5) shows two patterns regarding the density of frame generation moves. In the first pattern, frames are generated within a short period of time and often at the beginning of the ideation session. In 13 out of 18 design sessions, 50% of the frames are generated in only 10% of the total design time and the rest of the time is mostly spent on exploring these frames. This model is signified by a short period of high-density frame generation in which very limited time is spent on developing the frame. During these sections of the ideation session, designers avoid evaluating or exploring frames and instead focus on generating stories that explain the situation.

In the design theory literature, the divergent phase of the design process often pertains to the period in which designers generate design ideas that solve the design problem. The observation from this data indicates that a distinction should be made between frame and solution divergence in design sessions that focus on solving open-ended and complex problems. The analysis of these design sessions shows that designers engage in a divergent search for frames early in the design process. This period allows designers to conjecture as many stories as possible and to keep hypotheses open.

However, frames are not always generated in a concentrated pattern. In the second pattern, frame generation moves are diffused throughout the design process. Designers dwell on a frame to explore its potential after it has been initiated and the next frames are not generated immediately. In contrast to the concentrated model, this diffused model is signified by a gap between frame generation moves which is filled by an extensive exploration phase. Designers sequentially explore one frame before moving to the next one in this diffused model. Designers move within this frame until a new frame is generated. This model suggests a sequential pattern to the generation and evolution of frames.

For this analysis, we define the threshold value (T) to be equal to 10. The analysis of the design session shows that designers use different strategies to generate and explore frames (Table 3.2). Teams who used serial exploration strategies often generated fewer frames compared to the teams that used parallel or mixed strategies. Different frame generation strategies did not show an impact on the number of frames generated. In both the generation and exploration of frames, most designers used a mixture of the two strategies.

Design Session	Generation Strategy	Exploration Strategy	Number of Frames Generated
13	Diffused	Serial	2
1	Concentrated	Serial	3
9	Diffused	Serial	3
10	Mixed	Parallel	3
14	Diffused	Mixed	3
2	Mixed	Serial	4
3	Concentrated	Mixed (parallel first half)	4
8	Concentrated	Mixed (serial in the first half)	4
12	Diffused	Mixed (serial in the first half)	4
15	Mixed	Serial	4
16	Mixed	Mixed	4
11	Mixed*	Parallel	5
5	Concentrated	Mixed (parallel in the first half)	6
7	Diffused	Mixed	6
4	Mixed*	Mixed	7
6	Mixed*	Parallel	7

Table 3.2. Frame generation and exploration strategies (mixed generation strategies are concentrated at the beginning and diffused towards the end of the process)

Some of the teams who used the mixed exploration strategy started with a parallel exploration and continued with a serial strategy while some showed the reverse pattern. All design teams who used mixed generation strategies started with a concentrated approach at the beginning and continued with a diffused approach towards the end. This is compatible with our earlier observation that most frames are generated at the beginning of the ideation session and close in time to each other.

Qualitative Protocol Analysis of the Two Strategies

In this section, I will use snippets (selected examples) from two different design sessions to present an example of the concentrated and diffused frame generation pattern. The instance of concentrated frame generation has been selected from the ideation session number 6. This design session offers a good example of this pattern since during the first 19 moves of this ideation session five frames are generated in parallel with each other.

Concentrated Pattern

In the moves 1-3, Kara poses the following question: *Does* the *university educate students on how to find the blue light phones?* While the frame is brief and doesn't offer any supporting stories, it presents a viable hypothesis about the situation. Therefore, the frame has the potential to act as an attractor for new stories that can reinforce or challenge it. In the first move, Kara questions education around blue light phones and elaborates on the second move by adding a point from the brief (but students are aware that blue light phones exist). Therefore, Kara's frame questions whether enough education is provided by the university on how to find the blue light phones.

In move #4, Arjun shifts to a new frame by questioning the location of blue light phones without engaging with the first frame. This frame questions the location of blue light phones and whether they are "easy to find". Similar to the previous frame, no supporting story is offered but a point of exploration is initiated.

The third frame (moves 8-10) questions the visibility of blue light phone locations. The generative activity on the fourth frame (moves 11-16) involves a brief process of storytelling. At move #11, Kara tells a story by referencing her personal experience of the blue light phones:

> ***Move 11*** *I am so used to seeing them that they are just part of the environment … They are like a tree.*

This move is followed by another story by Arjun:

> **Move 12** I have seen them but I have never seen them and thought about them.

These stories lead to the fourth frame which is framed by Arjun as following:

> ***Move 13*** *Why did they choose this form? Because they are very similar to everything else we see.*

The last frame that emerges (moves 18-19) questions whether blue light phones are accessible to children. The analysis of design excerpts from this ideation session shows that 5 distinct design frames have emerged in 19 design moves. In these initial moves, Arjun and Kara generate and briefly elaborate multiple frames without exploring any particular solutions to the problem. Some of these frames (2 and 3) are generated without any prior supporting stories. Designers directly questioned different issues related to the blue light phones that in their opinion identified the problem. In other frames (1, 4, 5) designers engaged in a very brief process of story building. For instance, in frame 4, designers built the narrative on two short stories and in frame 5 an actor triggered the generation of the frame. In this pattern, the designer put forward as many narratives as possible to cover the range of possibilities within the situation. Designers allow themselves to generate multiple narratives that open up the path for exploration.

Excerpt ID	Excerpt	Frame Code	Designer ID
1	My first thought is … what is the education around this look like. is it from peer to peer? Is it [the] university doing some kind of education?	1	K
2	Clearly, students are aware of them. They are told at some point what these are.	1	K
3	Do they just say they exist and what they are for … or did they tell how to find them?	1	K
4	Location of these …. How do they determine the location of these things.	2	A
5	So yeah … what was the planning behind?	2	K
6	Yeah. how did they locate? Distances between them.	2	A
7	On the map it looks like, it is all on campus.	2	A
8	Visibility at some point?	3	A
9	Are these inside buildings/?	3	A
10	No, they are always outside. That is a parking deck …	3	K
11	In the night they light up so this is blue. But I do not know how strong the light is.	3	K
12	And I am also thinking about myself … I am so used to seeing them that they are just part of the environment. They are like a tree.	4	K
13	Yeah … I have never seen them. I have seen them but I have never seen them and thought about them.	4	A
14	I would be curious too about the design of them … did they design them as strip pole on purpose …	4	K
15	Why did they choose this form? Because they are very similar to everything else we see.	4	K
16	Are these all blue? Blue is because of the U of M?	4	A
17	No, if you go to any college campus it is the same thing.	4	K
18	So for design consideration the form but also the height.	4	K
19	Yeah but this is probably … for children as well.	5	A

20	Can they access it? Accessibility.	5	K

Table 3.3. First five frames generated in the design session #6

Diffused Pattern

The first 25 moves of ideation session 9 present an example of the diffused frame generation. In this session, one of the designers (*Nabil*) instantly offers a frame in the first couple of moves:

> ***Move 1*** *Why most students know the system but cannot locate it or cannot find it when they need, when they're in like an emergency probably has to do with the color itself.*
>
> ***Move 2*** *The blue color is not striking it all. It's not something that catches your attention as you walk past it. Um, that doesn't make you notice it because [it is] against the backdrop of the green.*

Nabil's proposition (color of the blue light phones doesn't catch the attention of students) offers an explanation of the situation which is also directed towards a solution. After this initial proposition, both designers started elaborating on the frame and also using it to generate ideas. Brenda provides a story to support the frame:

> ***Move 3*** *It is all cold color, but it's also like everything maze and blue. So another thing blue.*

This story uses different reasoning to support the same narrative. The first supporting story focuses on the low contrast between the color of the blue light phone and its background. Branda's supporting story points out that the university colors are blue and maize, and people won't notice another blue colored object. The difference between these two different supporting stories results in conflicts about the solution in the next two moves:

> ***Move 4*** *Maybe if it was green, people would notice.*
>
> ***Move 5*** *Well, I mean the problem with green again is that sits against the backdrop of trees like it, like here in the photo. It might just get camouflaged. Um. It's like against a brown building or a glass building, whatever.*

After this initial move, designers used other stories (10-12) to support and expand the narrative and generated ideas (using a sharp color, adding a funky design or an art installation) based on the frame. Through exploring different stories, designers expanded the scope of the frame from being merely about color to a general frame concerned with the "unnoticeable presence of the blue light phone". This process of exploring and expanding this initial narrative continues until move #25 in which a reflection on proposed solutions and a new idea disrupts the flow of this frame:

> ***Move 25*** *But people would not pay attention to that after a while.*
>
> ***Move 26*** *But if you get some kind of a path that shows where the closest emergency thing is at some other points and they could be changed once in a while because people just get used to it and they don't see that anymore.*

Excerpt ID	**Excerpt**	**Frame Code**	**Designer ID**
1	why most students know the system but cannot locate it or cannot find it when they need, when they're in like an emergency probably has to do with the color itself.	None	**N**
2	The blue color is not striking it all. It's not something that catches	1	**N**

	your attention as you walk past it. Um, that doesn't make you notice it because [it is] against the backdrop of the green.		
3	It is all cold color, but it's also like **everything maze and blue**. So another thing blue.	1	**B**
4	maybe if it was green, people would notice.	1	**B**
5	Well, I mean the problem with green again is that sits against the backdrop of trees like it, like here in the photo. It might just get camouflaged. Um. It's like against a brown building or a glass building, whatever.	1	**N**
6	It just seems like a part of like what you said part of the UMICH branding or the university branding, wherever it's located or seems just like any other thing that you might find in an urban setting.	1	**N**
7	But when it's like red and especially when the light would be red, I'm assuming they have a light or something, up on the top. It's something that you feel like gets your attention. Even if you're inside a car or passing by inside the car.	1	**N**
8	So I think color is one thing.	1	**B**
9	and the light I guess ... the color of light	1	**N**
10	I never saw any of those being used and I knew they existed, but I didn't even know how they were used. There's only one of them that I know where it is, or two of them.	1	**B**
11	For me, it would just be one. I can only give an estimate of the scale in which it's located down at central on the street that I'm talking about. Um, but then that's, that happens to be because I was like waiting for the bus a long time besides that, but just why it caught my attention.	1	**N**
12	But it's at night. I'm [in] central campus. It's not that widely lit at night if you're not on the main street or state street. So the blue kind of like, because even darker night. Which is another problem?	1	**N**
13	If it was red, it could still like stood out a bit more. An easy solution to this might be approaching this from color theory and how color affects the human mind because red always instills a sense of heightened sensitivity, alertness, and all that.	1	**N**
14	I agree and I thinking about color and like shape.	1	**B**
15	I understand that it has to be kind of similar for people to, to see parts of the same thing, spots of the same thing. but maybe if they were like kind of Funky, each of them had like a different color or a different illustration are different, different thing because I know when you break the, the common things people pay more attention. So if each of them had like a different type of story or something that people stopped to see. Uh,	1	**B**
16	I was going to see something like an art installation or something like that. Anything that grabs your attention but then not overpowering the original intention that is being able to help identify the phones.	1	**N**
17	But I was also thinking of how would it be if the noise was actually used to get more attention towards it. Like how you have the blue bus announcements when they stop. When they stop in front of Pierpont commons and you hear a voice going off the next step	1	**N**

	being someplace or some other place. So what if there was actually some sort of noise coming up from here that would actually make people take notice or something maybe a voice. I mean I'm sure there's a lot of research into how different noises or different sounds affect human behavior.		
18	I think that would be like applied over here instead of going into some really expensive or really elaborate or even a little bit more elaborate design features like physical design features. I think a lot could be solved by simple technology	1	**N**
23	So say what if I was walking past the street side and there were one of these emergency phone poles and they were light up as I walk past them instead of constantly being lit. So the turning on and turning off would actually [bring] some kind of disturbance to the normal environment. So the turning on and turning off will actually make people want to turn their heads and look what's turning on and turning off. So I think that's even much better.	1	**N**
24	It will also conserve energy. Like the light instead of being always lit on.	1	**N**
25	**But people would not pay attention to that after a while.**	**1**	**B**
26	But if you get **some kind of a path that shows where the closest emergency thing is** at some other points and they could be changed once in a while because people just get used to it and they don't see that anymore.	1	**B**

Table 3.4. First two frames generated in the design session #9

Discussion

In this chapter, we built upon the notion of storytelling to offer a model for analyzing the design process. Our model proposes that a design frame can be modeled as a narrative that creates an overarching structure around the stories created during the design process. This narrative structure has the potential to attract new stories that support or challenge them. This model was used to identify the frames created during 16 design sessions and the moves related to each frame. Mapping frames over the course of the design process made it possible to determine the moves during the design process that designers have generated a new frame or shifted between existing frames. These events were used to identify strategies for generating and exploring multiple frames during these design sessions. The results showed that half of the participating teams (n = 8) merely relied on diffused or concentrated strategies for generating design frames. The rest of the teams utilized a combination of both strategies by utilizing a concentrated strategy at the beginning and a diffused strategy towards the end of the design process. Similarly, half of the teams used parallel or serial strategies for exploring design frames and the other half used a mix of strategies during the design process.

Limitations

There are a few limitations associated with the approach for identifying frames from design protocols. First of all, frame-narratives are not always being made explicit during the design process. Based on their problem-solving strategy, designers might verbalize the stories they conceive or directly construct a frame or propose a solution. Research by Lawson (1979) shows that designers who take a problem-oriented strategy focus on structuring the problem before proposing the solution. In contrast, in the solution-oriented strategy designers generate and test solutions until a satisfactory result is obtained. Therefore, we expect the situation stories and narratives to be less explicit in design teams who utilize the solution-oriented strategy. This requires the analysis to identify a frame while the stories might be implicit. Second, narratives do not appear as consistent and uninterrupted structures during the discussions. Instead, narrative segments are often diffused throughout the conversations. To create a coherent narrative statement, these pieces need to be reorganized and reassembled. Each story is being re-constructed and negotiated in every design move. Finally, designers initiate multiple narratives that are developed simultaneously during the design process. This is in contrast with the notion of framing as a linear process in which a frame is created, reflected upon and negated before it is being replaced by a new frame.

To address the multiplicity and fragmentation of the narrative, we utilized a collaborative iterative coding process to identify the main narratives in the design session. To eliminate redundancies, the extracted narratives were compared against each other and similar narratives were combined into one. These narratives capture the core frames as established by the designers. Then these frames were used to code all design moves. This approach allowed us to extract and track the frames constructed during the ideation and their relationship with the generated ideas. The detailed coding procedure will be described in the method section.

Chapter 4 Reflections, Juncture Points and Reframing

Frames are structures constructed by designers to make sense of a situation and define their problems. Reframing is the process of replacing existing ways of understanding a situation with new ones. Kolko (2010, p. 4) defines reframing as "the act of purposefully shifting the normative frame … in order to see things from a new perspective". Paton and Dorst (2011, p. 575) describe reframing as "the adoption of new frames for interpreting the design context and task". Adikari et al. (2013, p. 9) offered a notion of reframing as the process of exploring "the same contextual situation from multiple perspectives to create new knowledge".

Previous studies have shown that the ability to reframe is a key design skill and central to creating innovative solutions (Dorst, 2011; Verganti and Norman, 2014). Reframing a problem improves the designer's understanding of the situation by opening new vantage points and creating awareness about different possibilities (Rappaport, 1986; Baldwell, 1991). Reframing also allows the designers to "challenge and overcome limiting beliefs ... and … worldview(s)" to develop new ideas and explore possibilities (Thorpe & Gamman, 2011, p. 258). By reframing a situation, designers enter a new design environment and imagine solutions that could not be conceived in the old framework. In this sense reframing is an effective way of overcoming fixation in design (Patton & Dorst, 2011).

Existing research in design notes that reframing is triggered by a disruption in the designer's perception of the problem. Such a disruption appears when designers reflect on the frame and identify a failure or unresponsiveness in its structure. Different studies have adopted different lenses to look at this disruption: 'surprise' (Schön, 1992; Dorst & Cross, 2001; Stompff et al, 2016), 'mood of dissatisfaction' (Cardoso et al., 2016) or 'conflict' (Rein & Schön, 1996; Stumpff & McDonnell, 2002; Hey et al, 2007). The uncertainty and ambiguity created by these moments of disruption are consequently resolved by transforming or adopting a new way of seeing the situation (Schön, 1992, p.125).

What Schön and others refer to as *surprise* can be a perceived error, anomaly, or opportunity (Schön, 1992) which creates a break from the routine design activities and drives the originality streak in design (Dorst & Cross, 2001). Stompff et al. (2016) suggest that surprise is caused either by a mismatch between the constructed frame and the situation or by the presentation of new opportunities in the situation.

The rhetorical approach characterizes reframing as a process of negotiating incongruous frames held by different parties involved in the design process (Rein & Schön, 1996; Stumpff & McDonnell, 2002; Hey et al, 2007). As the design starts, designers shape different frames depending on their perspective of the situation (Stumpff & McDonnell, 2002). Hey et al (2007, p.93) refers to this "initial understanding of the design situation" as a pseudo-frame. As the design process moves forward and pseudo-frames become more explicit, their differences also get more salient and conflicts arise. Designers resolve frame conflicts through a process of negotiation, argumentation, and persuasion (Hey et al, 2007). The result of this process is the consolidation of frames or shifting the frame to create a mutually acceptable frame (Stumpff & McDonnell, 2002). Cardoso et al. (2016) proposed that reframing is triggered by the designer's dissatisfaction with the existing perception of the problem or the way it is being addressed. This *mood of dissatisfaction* is the result of the designer's reflection on the generated ideas which can ultimately result in questioning the frame and reframing.

Central to all these junctures is an awareness of the frames and potential conflicts, anomalies, and opportunities in the situation. Such awareness is activated by reflecting on the design process and situation. These critical reflections are not singular and isolated events but the result of an ongoing process building upon preceding actions. Not all reflections, however, result in the emergence of critical junctures in design. Instead, reflections are often followed by slight modifications of the existing solutions or frames. This distinction has been highlighted in the data-frame theory of sensemaking (Klein et al., 2006). This theory states that making sense of an event starts with the creation of an initial frame (Moore & Hoffman, 2011, p.147) that guides what counts as data and how data are connected. As the person tries to use a frame to make sense of the situation, she encounters new data that doesn't fit into the frame. Frames are being questioned to challenge their inconsistencies with the data or the explanation of the situation they offer. To respond to these inconsistencies and anomalies, one might elaborate on the initial frame by seeking and adding new data and relationships and discarding the data that doesn't fit the frame. Alternatively, the frame can be rejected and replaced with a new one (Klein et al., 2006).

At the core of the data-frame theory's explanation of the reframing process is a distinction between reflections that trigger minor changes in perspective and the ones that result in a major change i.e. reframing. The purpose of this chapter is to look into the relationship between these modes of reflection by asking the following questions:

1. What is the role of reflections in moving the design process forwards and creating points of juncture?
2. What are the processes underlying the emergence of the critical reflections that define the turning points of the design process?

Research Approach

We approached these questions by analyzing the design protocols of two reframing episodes selected from the ideation sessions discussed in chapter 3. Both episodes start with the generation of a frame, followed by an extensive exploration of the frame, and conclude with a critical reflection and reframing. The model for identifying the design moves preceding the critical reflections in these two episodes was developed by building upon data-frame theory (Klein et al, 2006) and the story-narrative model presented in chapter 1. In the next section, a process-oriented coding scheme for analyzing the design protocol will be presented followed by the analysis results and a description of the reframing model.

Method

To approach the processes leading to this juncture points in the structure of the frame, three issues need to be addressed. First, we need a formal description of the frame structure to track its transformations over the course of the design process. Such a definition was offered in chapter 2 with a two-layer model of design in which frames are conceived as *narrative* structures connecting and assigning meaning to *stories* about existing and future situations. The first set of stories are concerned with *'how things are'* and the second set represents *'how things will be'*. The relationship between stories and narratives in this model is reciprocal. The narrative guides the kind of stories that designers look for in the situation. At the same time, it is also constantly being reshaped by the stream of stories incorporated into the design process. Thus, design involves both top-down and bottom-up processes. In top-down processing, frames impose a structure on the designer's understanding of the situation. In the bottom-up processing, stories elaborate and reshape the narrative by adding or modifying new actors and actions or discarding the existing ones.

The second problem is to offer a formal description of these two kinds of frame transformations discussed earlier in this chapter: modification and transformation. We approach this problem using the conception of the frame as a narrative (system of stories). In the first mode of transformation (*t*), a new story or a set of story elements (actor, action, attribute, affordance) are added to the narrative or new connections are established between existing stories while retaining the overall structure of the narrative. The second mode of transformation (*T*) goes beyond elaboration and replaces the narrative with a completely new one (i.e. reframing). The new narrative doesn't necessarily bring a new set of stories or story elements but a new way of seeing the same stories.

Finally, we need to account for the relationship between frames and the solutions generated within them. Frames structure the designer's understanding of the situation and present problems to be solved. However, problems and solutions are not isolated entities shaped during different episodes of the design process. Instead, they constantly interact with each other and co-evolve as problems are being reshaped by the solutions and solutions respond to the changing structure of the problem (Cross & Dorst, 2001). Frames are not only transformed by reflecting on their internal structure but also through interaction with the evolving solutions. Therefore, the frame transformation can't be studied independently of solutions. To approach this issue, we included solution-oriented activities in our model to account for their interaction with the frame.

Model and Coding Scheme

A model and a process-oriented coding scheme were defined to systematically identify design actions in a reframing episode. The coding scheme focuses on the actions and strategies utilized by the designer to solve a problem using predefined categories (Dorst & Dijkhuis, 1995) built upon a three-level model of design actions (Figure 4.1). The first level distinguishes between the moves that focus on understanding the situation to build a narrative and moves aimed at using the narrative to generate the solution.

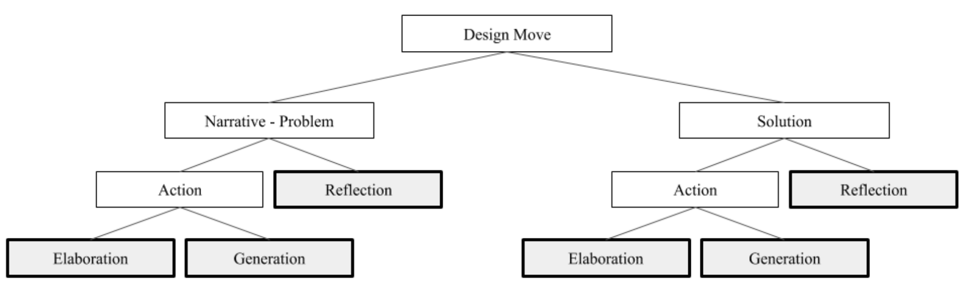

Figure 4.1. Three levels of distinction in the design model

On the second level, a distinction is made between action-oriented and reflection-oriented design moves. The distinction and interaction between these two are central to the theory of reflective practice. We propose that action and reflection take place in both narrative and solution. Finally, we differentiate between actions that modify and elaborate a narrative or a solution (*t*) and the ones that completely transform it (*T*). Based on these three distinctions, we defined six action categories in our coding scheme. On both the narrative and solution levels, three activities are identified: generating, elaborating and reflecting (Table 4.1).

Design Activity	Description
Generating Narratives	Proposing a new understanding of the situation to generate a fresh narrative
Elaborating Narratives	Elaborating or restructuring the narrative by adding, removing or modifying stories or elements of the story
Reflecting on Narratives	Questioning narratives to evaluate their internal validity, correspondence to stories, and potential for generating effective solutions
Generating Solutions	Proposing a new solution within the narrative to constitutes a future situation
Elaborating Solutions	Modifying a solution by adding or removing elements such as actors, actions, or affordances.
Reflecting on Solutions	Questioning solutions to evaluate their viability, correspondence to narrative and effectiveness in solving the problem.

4.1. Activity-oriented coding scheme

Empirical Study

To address the research questions, a micro-level protocol analysis was conducted of two reframing episodes using the coding scheme. These reframing episodes were selected from the design protocol dataset described in chapter 2. Sixteen ideation sessions were explored to identify episodes in which designers initiated and explored a frame before replacing it with a new one. The selected episodes offer a condensed view of the processes involving the reframing of the design situation. The author segmented each episode into 'moves' using the procedure described in chapter 2 and used six predefined categories from the coding scheme to code each move.

Results

In this section, an overview of the results of the protocol analysis is presented followed by a detailed look at the two episodes. An example of the full analysis can be found in appendix III. Table 4.2 shows the quantity and ratio of moves in each category in two episodes. Designers in episode 1 utilized more than half of the moves to elaborate the narrative before generating a solution. In contrast, in episode 2, designers directly started generating solutions after building the narrative. While the first episode is focused on developing the narrative (72.6% of moves towards the narrative) the second episode is focused on the solution (92.7% moves towards the solutions). In both episodes, the number of reflection-on-solutions moves is higher than the reflection-on-narrative moves. Also, the number of solution elaboration moves is higher than the solution generation moves in both episodes.

Design Episode Index	Total number of moves	Generating Narratives	Elaborating Narratives	Reflecting on Narratives	Generating Solutions	Elaborating Solutions	Reflecting on Solutions
1	92	11	54	2	6	11	8
		11.9%	58.6%	2.1%	6.5%	11.9%	8.6%
2	42	2	0	1	5	17	17
		4.7%	0%	2.3%	11.9%	40.4%	40.4%

Table 4.2. The quantity and ratio of moves in each category in two episodes

Episode A

Designers in ideation session 1 (Jaipeng and Shila) started the process by discussing relevant ‘stakeholders’ in the situation. The term ‘stakeholders’ was used to refer to the potential users of the blue light phone or the *actors* of the story. After discussing which actors should be included in the design scope, Jaipeng initiated a narrative by bringing attention to the recognizability of the blue light phones [Move 28]: *"We can think about different factors which make the blue light telephones recognizable".* While minimal, the focus on *recognizability* affordance provides a framework for developing a narrative. After naming a few attributes which can contribute to recognizability (e.g. size, color, height), Jaipeng suggests *location* as an attribute contributing to the *recognizability* of the blue light phone: "*So, one of the things I would consider [would be] the location … where are they located?"* [Move 33] This move connects the recognizability of blue light phones with a concrete attribute (location) and diagnoses a problematic situation which can be summarized as follows: Students can't find the blue light phone since they are not located in locations that make them recognizable. This narrative of the situation guides the following moves by guiding the designers' attention to locations in which blue light phones are located.

With this narrative in hand, designers start expanding and elaborating on the narrative by exploring the *locations* where the blue light phones are located. Using the map that was provided as part of the brief, several locations were identified (e.g. parking, main roads, and campus buildings). For instance, Jaipeng discusses a new story involving the 'main road' [Move 39]: "*Is it on the main road? Suppose someone is following me, I would not start to run out on the main road."* This move offers a tangible story involving a human (attacker) and non-human actors (main road) and actions (being chased and running) which elaborate and specifies the narrative. The story allows the designer to imagine how the situation unfolds given the actors and interactions. While this process was initially exclusively exploratory, designers gradually started reflecting on the *"the logic"* behind these locations. These questions reflected on the choices made about the location of blue light phones. In moves 63 and 65, Jaipeng questions the location of a blue light phone located next to the river: *'What is this one? Is it completely separated from all the others? … if I am in here, why would I [use this one]?'* A similar question is asked about the blue light phones located in the parking lot (*'Why would you have it inside where people cannot even see it?'),* next to an educational building (*'if this is the building and most students are leaving from here. There is no point having them [telephones] in here.')* and next to a sports facility: 'so *why would anyone want to travel this way … people are more likely to travel like this … if they want to go here …?'*

These evaluative reflections on the situation reinforce the narrative about the problem with the location of blue light phones. They confirm that the location of blue light phones is problematic and not effective in helping the actors to find them. Jaipeng ends these series of reflections by concluding that *'the location of blue light phones is random'* and Shila confirms that *'there is no logic behind it*'. By defining these stories and reflecting upon them, designers reinforced the narrative that the location of blue light phones *'has no logic'* and to solve the problem of blue light phones should be moved to locations that are *'recognizable'*.

Designers start proposing solutions beginning at move 132. Two attributes guide the direction of design solutions. First, Jaipeng proposes that to improve recognizability they should focus on locations that are *'frequently-visited'.* This concept of 'frequently-visited locations' becomes central to the solution generation since it offers a concrete attribute for design solutions. Second, Jaipeng proposed that to make the locations '*easy-to-remember*', the location of the blue light phones should follow a *'standard'.*

Following this concept of 'standard', Shila proposes *'entrance and exit points'* as the location of blue light phones since these are *'where everyone passes through'*. Jaipeng followed up with a new solution within the same line of narrative:

> ***Move 132*** *People tend to remember the location of washrooms and … So maybe having a standard that whenever you have a washroom there is a blue light telephone next to it. Wherever there is a bus stop there is a blue light telephone next to it. So that people really do not have to search for blue light telephones but they search for those common places.*

This idea is further developed as the designers explore these 'common' and 'easy-to-remember' locations including washrooms, water fountains, and the front desk.

So far, the design has been mainly focused on exploring solutions. However, designers start challenging the solutions which trigger the elaboration of existing ideas. In move 143, Jaipeng reflects on the existing solutions: *'but these [solutions] are for inside … nothing for outside'.* Later Shila challenges the solution for the parking lot because of their concentration on the entrances: *"You mentioned the entrance of parking lots but like this picture, we have big parking lot here … I am thinking about this situation … that parking lot is very big and they do not have access to the entrance or the ticket kiosk."* In both moves, designers reflect on the solution by adding situations in which the current solutions don't stand ('*outside of buildings'* and '*big parking lots'*). At the same time, designers expand the scope of design by adding new actors. The challenge with the parking lots triggered the elaboration of the solutions. Jaipeng proposes that blue light phones should be placed at points in the big parking lot where the '*vehicle always passes'* or at '*equal distance'* from both entrances.

After this cycle of reflection-on-solution and elaborating on the solutions, Jaipeng reflects on the narrative which fundamentally challenges the approach. He asserts that all solutions are designed to help users *'remember'* the location of blue light phones. This is due to the fact that they are operating within a narrative based on locating blue light phones in *'easy-to-remember'* locations that are *'frequently-visited'*. However, when it comes to the new situation (big parking lots) the approach seems to be insufficient: *"How would they remember where it is? If we have it in the middle [of the parking lot], how do they remember? … locatability comes only when people can remember where it is."* While these reflections initially questioned the effectiveness of solutions in responding to the problem, on a higher level, they point out the limitations of the current narrative in the creation of solutions.

To respond to this reflection, Shila proposes a shift from *'remembering'* the location of blue light phones to *'seeing'* the blue light phone. The following moves show how these reflections triggered the generation of a new narrative:

> ***Move 154*** *But they have to remember. How would they remember where is it, if we have it in the middle, how do they remember?*
>
> ***Move 155*** *OK, so we have … we can have two … here … how they can remember?*

Move 156 *So locatability comes only when people can remember where it is. It can only be …*

Move 157 *Or you can see.*

Move 158 *Yes … right? How will they be able to see?*

Episode B

Designers in the ideation session 2 (Skylar and Zoya) started their session by *'clarifying the brief'* and articulating *'use cases'* which guides them in constructing the narrative. In the initial moves [1-8], designers define their goal "*what they require … to basically guide them (students) to locate this thing [blue light phone]'*. Setting an early narrative, designers start paying attention to the ways in which '*students'* can be *'guided'* to find the closest blue light phone. To elaborate on this initial narrative, Zoya suggests that they need to think about some *'use cases':*

Move 14 *The student is walking along the road.*

Move 15 *Suddenly at this moment, he [becomes] very nervous. He is in this emergency situation. He won't have too much time to find this phone.*

This story allows the designers to animate the situation and to put themselves in the shoes of the users. It also makes the general narrative more specific and situates the actor. Reflecting on this story, Zoya asks the following question: *'for a normal student- what device he is carrying?'* This question aims to explore the potential of these devices in 'guiding' the students.

After naming a wallet, watch and phone as such devices, Zoya challenges this idea after a few moves: *'... in a very urgent situation if you pick up a phone and then normally open an app and search for something it will take a long time'.* This reflection discards the potential of these actors (wallet, watch, phone) in addressing the problem. To respond to this challenge, Skylar offers a new approach within the same narrative:

> ***Move 22*** So I think it should be something that is visual to him. Wherever he is looking he should be able to see a sign that he should go this way to access the telephone system.

The initial approach ('*using devices such as a phone'*) was questioned *('it takes a lot of time'*) and a new direction was proposed and replaced by a new one ('*something that is visual to him ... wherever he is looking, he should be able to see a sign'*). While designers are staying within the same narrative ('*guiding the students to find the closest blue light phone'),* this approach delegates the act of 'guiding' from the initial actors ('devices carried by the students') to a new actor (environment). In this process, the initial narrative has been enriched and expanded with new stories, actors and actions. Designers engaged with this strategic direction for the rest of the episode. Skylar presents the first solution within the new solution approach:

> ***Move 23*** One way would be to have a lighting system with arrow patterns on the floor. It is

somewhere within this area. So all those will point
to these telephone systems.

The introduction of the second idea in move 25 by Skylar triggers a cycle of evaluative reflections and solution elaborations. Zoya reflects on this solution [move 26] by questioning the visibility of the lights (*'hard to see'*) in a new situation (*'darkness of night'*). To respond to this challenge, Skylar elaborates on the existing solution and a new actor ('glowing material') to solve the problem. In move 28, Zoya again challenges this solution ('*but it can be distracting*') which results in the creation of a new criterion by Skylar: '*it has to be **easily seen** but also **not spoil the landscape***.' To respond to this challenge Zoya elaborates on the solution: *'What if the student sends out the prompt saying he is in danger and then these lights will show'*. Here a new interaction (*'sending prompt to turn on the lights'*) is introduced and elaborated in the next moves [31-33].

In the following moves, similar back and forths occurred between designers. Through this process of reflection and action, designers elaborated on the initial idea and added new stories to the narrative. Zoya brings up new stories to reflect on the solutions. These stories expand the stories that constitute the frame narrative (night situation) and suggest new relationships between the actors (arrows are distracting for the pedestrian). To respond to these challenges, Zoya adds and modifies the existing elements of the solution.

This cycle of solution elaboration and evaluative reflection continues for the rest of the narrative. The two designers constantly question the solutions by animating different situations and propose new elaborations to solve the problem. At move 81, Zoya suggests moving to a new approach:

> ***Move 81*** *So maybe you will be better off to think from the other side … how we can help them to easily find it … instead of making it distinct.*

This shift in the narrative defines a new direction for design in which the focus is on making the blue light phones visually distinct.

Discussion

This chapter presented a protocol analysis of two reframing episodes selected from two different ideation sessions. Specifically, we examined the function of reflections in creating juncture points that trigger reframing. At the beginning of the design process, designers seek to understand the situation and construct a frame-narrative based on such understanding. The reflections at this point are mainly focused on descriptive (what is going on?) and diagnostic questions (what is problematic about this situation?). After a frame-narrative is established, designers start generating, elaborating and reflecting on solutions. Hence, the focus of attention shifts to generating solutions and asking perspective (*'how things can be?')* and predictive questions (*'how things will be?').* In both episodes, designers extensively explored the frame before coming up with a new frame.

To reflect on these future situations, designers ran ‘mental simulations’ (Escalas, 2004) which allows them to imagine how events unfold given the narrative and the solution. These mental simulations are presented as stories that “play out plausible interactions in a more-or-less lawful virtual world.” (Pinker, 2007). Running such simulations allows designers to explore the potentials of the narrative for generating the solution and on the other hand to see new stories and situations that were originally unnoticed. It is through narrative thinking that designers discuss *‘how things can be’* given their proposed solution and reflect upon them.

Designers can then reflect on such imagined stories to evaluate the solution. Reflection-on-solution evaluates and questions the effectiveness of the solutions within the current narrative. In our analysis, such reflections presented themselves in three ways:

1. First, reflections highlighted the inadequacy of the solution in addressing the problem. For instance, in the first design episode, Shila reflects on the idea of having blue light phones at the parking entrance and exit: ‘*That parking lot is very big and they do not have access to the entrance or the ticket kiosk.’*
2. Reflections can also highlight the unintended future consequences of the solution. In the second design episode, Zoya challenges the idea of having reflective materials for the blue light phone guides: ‘*But it can be distracting.*’
3. Finally, reflections can make the designers see new situations not considered in the original conception of the solution. To evaluate the effectiveness of a solution, designers look more widely for situations that were unnoticed originally. In the first episode, by bringing up *‘big parking lot’,* Shila challenges the existing solutions through an

unnoticed actor. In the second episode, Zoya mentions the 'night situation' to challenge the visibility of arrow guides.

In all types of evaluative reflection, designers problematize the solutions and expand the boundaries of the narrative by adding new problematic stories or elements. In the former, designers introduce new problematic elements that don't allow the solution to solve the problem and in the latter, new stories problematize the solution. To respond to these challenges, designers elaborate on the existing solution or propose new ones. Alternatively, designers might drop the current narrative and replace it with a new one. The question here is under what conditions designers reframe and move to a new narrative instead of elaborating on the existing solutions or generating new solutions within the existing narrative? We propose that the aggregation of small reflections on the solution leads to big reflections which ultimately trigger reframing. Reflections disrupt the structure of narrative in two ways:

1. Designers initiate a narrative with a limited number of stories that they conceive early in the process. However, as they reflect on solutions generated within this narrative, new situations and stories show up that were not considered originally. Designers try to fit these new stories in the existing narrative and to explain them using the diagnosis offered by the narrative. This process expands the boundaries of the stories that should fit into the narrative. With the growing number of these stories, designers might perceive a disruption in which the diagnosis offered by the narrative is not adequate for explaining the situations.
2. The second way that reflection disrupts a narrative is by questioning the effectiveness of the solution generated within the narrative. Reflections problematize the solutions within the narrative by highlighting their unintended consequences or their failure in satisfying the

requirements. As these problematic elements or stories expand, designers respond by proposing new solutions or elaborating the existing ones within the same narrative. However, with the expansion of the narrative, solutions can be perceived as inadequate in their response to the situation. The number of stories unaddressed by the solution increases over time and the solutions generated within the narrative seem to be increasingly insufficient. Accumulation of small reflections on the level of solutions (r-small) and persistent failure of the existing narrative in generating adequate solutions trigger a larger reflection on the direction of the solutions or on a higher level of the narrative (R-big), and the search for a new narrative. Designers recognize a limitation in the way the current narrative environment allows them to work towards the solution and attempt reframing.

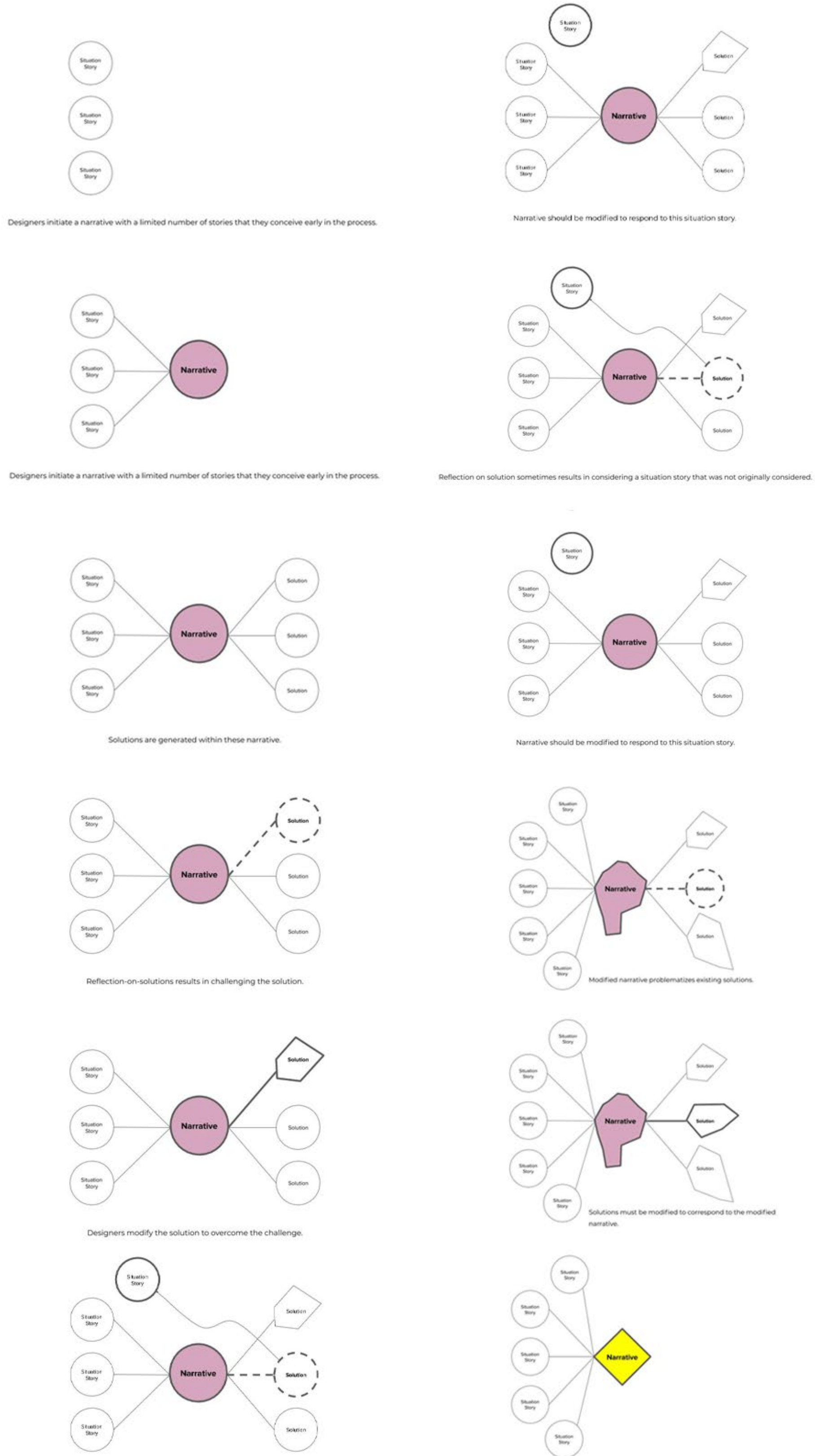

Figure 4.2. Diagram of a reframing scenario

At the core of this model of reframing are two levels of reflection. Lower-level reflections (r-small) challenge the solution and often trigger an elaboration of the solution within the existing narrative. Accumulation of low-level reflections triggers a higher-level reflection (R-big) on the entirety of the narrative that causes a moment of disruption and is resolved through a shift in the frame. In both cases, a cycle of reflection and elaboration preceded the juncture point and reframing. Such moments are the result of multiple reflections that have already challenged the solutions and expanded the narrative. Awareness of the limitations of the existing narratives loosens their structures and allows the designers to explore and adopt a new narrative. At this point, designers might generate a new narrative or adopt one of the unexplored existing narratives. This results in a new way of looking at the existing stories and introducing a new direction for action.

Chapter 5 Temporal Analysis of Semantic Network

The dual-processing model of cognition draws a distinction between the two modes of information processing. The first mode is automatic (Bargh, 1989), experiential (Epstein, 1983), fast and unconscious (Kahneman, 2011) and relies on associative and similarity-based reasoning (Sloman, 1996). The second mode is slow, conscious, and deliberate (Frankish, 2010; Kahneman, 2012; Evans, 2008) and applies rational and analytical reasoning (Epstein, 1983). Dual-processing models have been utilized for analyzing decision making, judgment, reasoning and social cognition (Evans, 2008). These theories have also been extensively applied to the analysis of creative thinking (Sowden, Pringle & Gabora, 2015). The dual-processing models of creativity propose that similar to everyday thinking, creativity demands an interaction between two modes of thought.

A range of binary concepts have been proposed for describing these two modes of thought: divergent and convergent (Guilford, 1957), generative and exploratory (Finke et al., 1992), generative and evaluative (Ellamil, Dobson, Beeman & Christoff, 2012), and exploratory and exploitative (Bhooshan, 2017). Despite the differences between these models, a common feature can be identified in their description of the two processes. The first mode of thinking expands the boundaries of the design space and creates new ideas. Divergent thinking has been defined as the individual's ability to generate multiple solutions to a problem (Guilford, 1957) and multiple "associations to an idea" (Kleibeuker, De Dreu & Crone, 2013, p.3). Similarly, generative thinking in the geneplore model of creativity (Finke et al., 1992) involves creating new patterns, forms, and models (i.e. preinventive structures). Ideation has been defined "as the process of generating or conceiving of ideas and concepts that may be useful for attaining some desired state or outcome" (Briggs & Reinig, 2007, p. 1), as well as the process of "generation of options without evaluation" (Basadur et al., 2000, p. 80).

The second mode of thought evaluates and explores the potential of generated ideas. Basadure et al. (1982, p. 44) suggest that ideation is followed by "the application of judgment to the generated ideas to select the best one(s)". Convergent thinking is often described as an evaluative and analytical mode that focuses on discovering the relationship between information and finding the best solution (Guilford, 1967; Runco, 2003). During the exploration phase of the geneplore model, designers interpret preinventive structures, evaluate their potential for solving the design problems, and search for their limitations (Finke et al., 1992).

In the early literature, the two modes of thought were modeled as distinct phases of the design process: designers generate multiple solutions during the divergent phase and evaluate and select the best solution during the convergent phase. However, the empirical evidence on creativity suggests that the two modes of thinking are not separate steps but intertwined processes. Designers constantly generate and evaluate ideas by shifting between the two modes of thinking (Pugh, 1991). Goldschmidt (2016) suggests that divergent and convergent thinking occur concurrently during ideation. Therefore, the design process has been portrayed as a series of iterative loops (Dym, Agogino, Eris, Frey, & Leifer, 2005) or cycles (Liu et al., 2003; Dong, 2007) of divergent and convergent thinking.

To understand the patterns underlying the creative process we need to be able to map these intertwined cognitive processes on a micro level and with high fidelity (Goldschmidt, 2016). Micro-level analysis of the design process is often conducted using protocol analysis, a method which involves recording and transcribing the design conversations followed by breaking them into short segments and coding segments with predefined categories.

Results of the design protocol analysis are often presented as a temporal sequence or a network structure. The temporal approach represents moves sequentially with the X-axis showing the move index and the Y-axis representing the cognitive process (D'souza & Dastmalchi, 2016). The network approach represents the structure of the design process based on the perceived relations between cognitive processes (Goldschmidt, 1992; Kim & Kim, 2015). Design moves are presented with nodes and their connections are depicted with links.

One of the approaches for representing the structure and content of the design knowledge is to use networks. Being applied for describing a variety of structures ranging from societies and organizations to nervous systems and computing machines, networks have been used extensively in cognitive psychology for representing knowledge. The network approach asserts that knowledge is organized through interconnected concepts. An individual's domain of concepts grows and concepts get more connected through experience and learning (Maria Araceli Ruiz-Primo, 2004). Therefore, knowledge can be presented using a graph with concepts as nodes and their connections as links. Network representations extract the individual or team's knowledge about a topic by mapping concepts that are semantically connected in their system of knowledge. Concept maps and mind maps are two well-known content-oriented approaches for network representation of knowledge that have been utilized by design researchers to map out the design space as perceived and constructed by designers.

The concept map is a network diagram that organizes concepts and their connections in a hierarchical structure (Novak, 1990). Concept maps consist of three main elements: concepts (nodes), relationships (directional links), and propositions (link labels). The construction of the map starts with placing general concepts at the top and moves towards more specific concepts at the bottom.

Mind mapping (Buzan & Buzan, 1993) illustrates the concepts associated with a problem using a tree-like network structure. To construct a mind map, the topic of interest is placed at the center of a page and participants are asked to note related concepts and make associations between them. More recently, Kokotovich (2008) has developed a new model of mind mapping that removes the constraints imposed by hierarchical mapping to reach a more flexible network structure.

Concept mapping and mind mapping has been used for the assessment of an individual's knowledge of a domain or their creativity. Table 5.1 shows a variety of measures that have been developed to evaluate network representations of knowledge structure. Experts are characterized by having a highly elaborated and integrated knowledge structure which facilitates their decision making and problem-solving process (Yin, Vanides, Ruiz-Primo, Ayala & Shavelson, 2005; Chi, Glaser, & Far, 1988; Mintzes, Wandersee, & Novak,1997; Baxter, Elder, & Glaser, 1996). Novak and Gowin (1982) used the levels of hierarchy and the interlinks between them to evaluate concept maps. Kennett et al. (2014) have found that creative individuals generate semantic networks that are more flexible and contain broader associations.

Measure	Definition	Author(s)
Hierarchy	The number of levels of concepts in a map	Novak and Gowin (1984); Tan, Erdimez & Zimmerman (2017)
Crosslink	The links that connect one level of concepts to another one	
Integration	The total number of cross-links	Kwok & Vogel, (2002)
Complexity	The total number of direct-links in the associated concept map	
Comprehensiveness	The total number of concepts in a map	Nadkarni and Narayanan (2007)
Centrality	The total number of incoming and outgoing links	Hao et al. (2010)
Density	The total number of links divided by the total number of concepts	Hao et al. (2010)
Average entropy	Average entropy of all nodes in the map	Hao et al. (2010)
Structure of clusters	Island of themes	Eden (2004)

Table 5.1. Measures for evaluating the network representations of knowledge structure

Research Approach

Central to the process-oriented approaches for modeling design is a separation of the design process from its content. As suggested by Goldschmidt (1990, p. 291) the premise of a process-oriented analysis is that the "structure of reasoning is independent of content attributes of its components". Process-oriented models represent the structure of cognitive processes without identifying its relationship to the design content. Design moves are coded into processes using a coding scheme, and the relationship between the design process and its content is masked.

Content-oriented approaches are focused on extracting, representing, and analyzing the content and structure of the design space and not the order through which they have emerged. As process-oriented models of design ignore the design content, these content-oriented models mask the processes through which these structures have been generated. Therefore, the design space is depicted as a static structure. However, the design space can be studied as a dynamic structure built through a sequence of moves enacted progressively through the words and actions of designers. In this section, we present a model that draws upon this dynamic vision of the design space to connect the content-oriented and process-oriented approaches. Our model represents the content of the design space and, at the same time, its sequential transformation during the design process.

The purpose of this chapter is to address this gap by proposing a model for analyzing design which depicts cognitive processes not through subjective coding but from the shifts in the structure of the design content. The main premise of this approach is that shifts in the structure of the design content reflect divergent and convergent processes. To track these transitions, we propose a semi-automated approach for analyzing design protocols based on a semantic network representation of the design content. Semantic networks representation enables us to quantitatively describe the transformations of the design content which then can be translated into cognitive processes. Using this approach enables us to study and compare temporal cycles, trends, and ratios of divergent and convergent moves in a design process.

This approach allows us to analyze how design moves transform and (re)structure design space. Leveraging the potential of networks in representing changes in the structure and content of knowledge, the premise of this model is that the transformation of the semantic network constructed from the conversations between the designers reflects the underlying cognitive processes. Utilizing text analysis techniques, this model maps out the conversation between designers as semantic networks and enables access to the semantic space at any point during the design process to analyze the transformation of its structure and content.

In this chapter, a method for analyzing the design process is introduced which models the design content as a sequence of semantic networks developing through the design process. Next, the results are presented of analyzing the cognitive processes in the ideation sessions of 16 design teams using this model. Finally, the implications of this study for the research in the design process will be discussed.

Method

To formally describe the shifts in design content over time, a workflow is proposed for building sequential semantic networks from conversations between designers during ideation sessions. This workflow requires a different approach from the methods discussed earlier in this chapter (e.g. mind maps and concept maps) since the sequence of graphs are built from conversation transcripts after the design process and not directly by participants. As Carley and Palmquist (1992) pointed out, building network representations from textual documents is a process that involves identifying what counts as a concept and defining possible kinds of relationships between these concepts. However, our aim is not merely to represent the design protocol as a network of concepts but to study how each design move transforms the semantic network. We model design conversations not as a single matrix but as a sequence of matrices to elicit the shifts in the network over time. Therefore, the unit of analysis by which segments of design are distinguished also needs to be identified.

Concepts: Story Elements

As the first step, categories considered to be concepts in the conversations should be defined. Network structures are generic structures that can accept any entities as nodes. While these characteristics of networks make them capable of illustrating a variety of structures; at the same time, networks don't guide us as to the kind of elements that we should identify. Therefore, as a starting point, we return to the narrative approach for representing a design, as discussed in chapter 2. Narrative representation of knowledge has been adopted by researchers in both cognitivist (Minsky, 2007) and constructivist (Brunner, 1991) traditions. Brunner (1991) proposed that human experience and memory is mainly organized as narratives that "represent a version of reality" (p.4). In his theory of artificial intelligence, Minsky (2007) discusses narrative scripts as the most familiar way of representing knowledge which depicts a "sequence of events in time." However, Minsky (1974) argues that instead of describing the sequence of events, representation of knowledge can focus on the relations between parts. Semantic networks are an example of such a relational representation since they simplify knowledge to its most basic elements and their connections. While a story has a temporal structure, its elements can be extracted and rearranged in a network structure. Minsky suggests that network structures can be derived from narratives. However, the question is what elements should be extracted from the narrative to best represent the design world (Schön, 1983) as constructed by designers.

A theoretical approach that provides a framework for connecting the narrative and network representation of design is Actor-Network-Theory. As a conceptual framework, Actor-Network Theory offers useful concepts for describing the design world and the role that artifacts play in mediating action (Latour, 2005). To build this taxonomy, we adopted four concepts from Actor-Network Theory: actors, actions, affordances, and attributes. While these concepts have been discussed in other theoretical frameworks, Actor-Network Theory offers a synthesis to explain the structure and dynamics of socio-technical systems (Latour, 1990; Akrich, 1992; Yaneva, 2009).

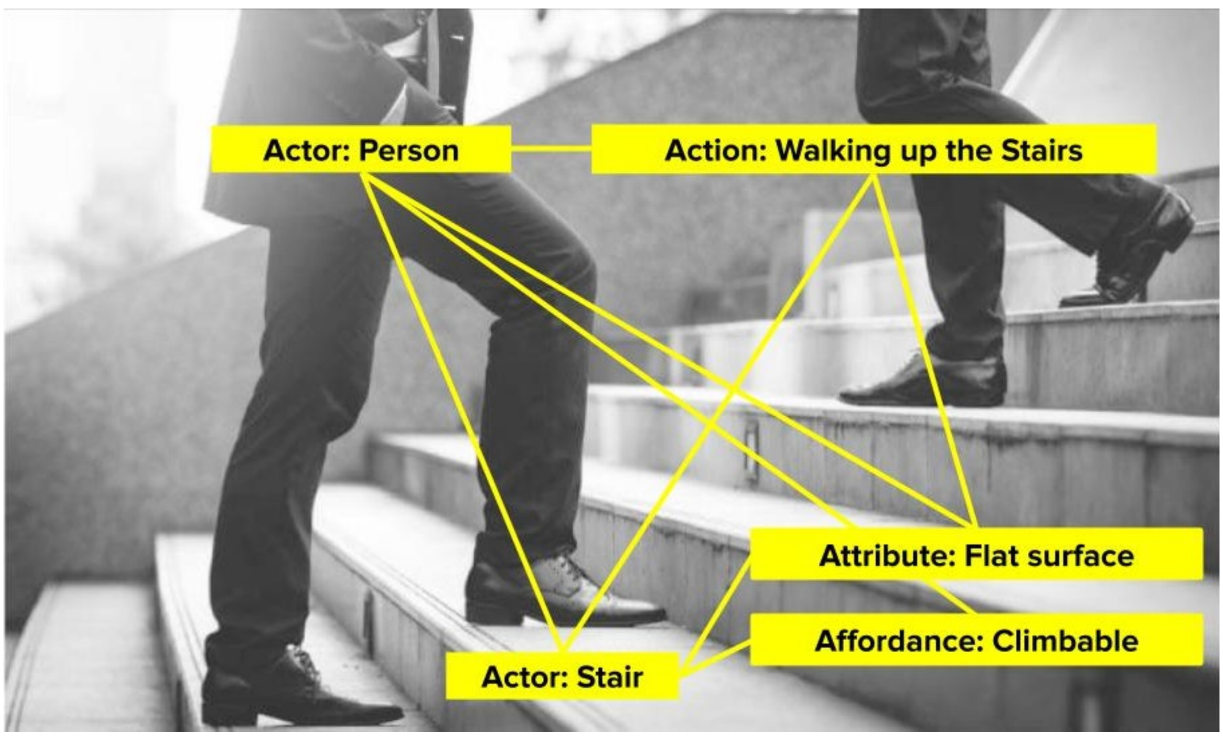

Figure 5.1. Concepts constituting the analysis framework

Actor-Network Theory situates scripts or scenarios at the core of design activity. Animated by the actions of an organized and connected collective of human and nonhuman actors (Callon, 2004), scripts illustrate how designers imagine the events in the world to unfold given their object of design (Akrich, 1992). Design is the process of creating a script or scenario and inscribing it in "the technical content of the new object" (Akrich, 1992, p.208).

The script is actualized through the actions of a network of human and non-human actors. The agency of actions is therefore distributed within this network. When used for non-humans, the agency doesn't refer to the capacity for intentional action but to the ways in which "the material world pushes back on people because of its physical structure and design" (Latour, 1992). The material structure of the environment enables different modes of action, reconfigures human agency, and mediates actions (Callon, 2004). This active role of the environment in shaping actions can be traced back to the work of ecological psychologist James Gibson who asserted that actions must be conceptualized within the "dynamic coupling between the animal and its environment" (Hutchins, 2010). Actions are enabled by the *affordances* of an environment i.e. "what it offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 1979). Similarly, in Actor-Network Theory, the concept of promission has been used to refer to what an artifact allows (permission) and what it suggests (promise) (Callon, 2004).

Affordance is not an inherent physical quality of the environment neither a mere subjective perception but a hybrid concept that offers an alternative to the subject-object dualities and suggests a complementary relationship between the animal and the environment (Gibson, 1979). What physical qualities an environment affords to an animal are specific, relational and defined by the coupling of the structure of an environment and an animal.

In summary, the scenario or script defines actors (human and non-human) that act in certain ways or make the actions of other actors possible through the affordances defined by their attributes (Yaneva, 2009). A person (actor) moving up (action) a ladder (actor) is made possible by the affordance (climbability) of the ladder which is actualized by the width, material strength and height (attributes) of the ladder's steps. The semantic space can be presented as a network of words representing the elements of design stories (actors and their actions), affordances, and attributes. Designers use new words to describe these new stories or story elements of the situation. In our approach, no limitation is set on the connections between entities and all entities can potentially connect with each other.

Relations: Co-occurrence in a move

After defining the concepts of interest in a conversation, we need to determine what constitutes the relationships between these concepts. To approach this issue, we will utilize the word co-occurrence, a widely-used method in natural language processing. The co-occurrence for measuring the connectedness of concepts assumes that:

a) Two words are related if they have been used in the same context. The context here refers to any segment of the corpus that is taken as the unit of analysis e.g. sentence, paragraph.

b) If two words occur multiple times in the same context, they are more strongly connected.

Using this approach, a co-occurrence matrix of words can be built. The co-occurrence matrix (M) consists of R rows and C columns (R=C). The value of cell M_{rc} refers to the number of times words E_r and E_c have been used in the same context. The higher this value the more connected are the two words. The co-occurrence matrix can be translated into a weighted network with nodes as words and links as the values.

The context in our analysis of word co-occurrence is the *design move*. As defined in the previous chapters, design moves are small scale units of cognition that present a situation, an idea, a question or an evaluation. Therefore, these two concepts are related if they co-occur within a design move. Moves also define the sequence of events in our model. Every move can add new nodes or links to the structure or reinforce existing links. The conversation consists of a

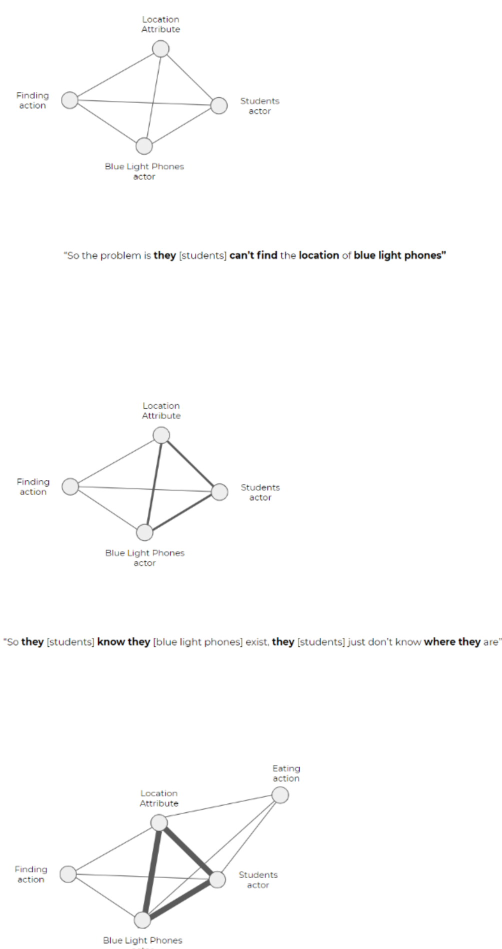

Figure 5.2 . An example of building a graph from a design conversation

sequence of moves that expand the semantic network and reconfigure the relationships between concepts (Figure 5.2)

Empirical Study

To explore the potential of this model in analyzing cognitive processes in design, 16 design protocols (collected as described in chapter 3) were analyzed using the following procedure:

1. Verbal communications during the design process were recorded and transcribed.
2. The design protocol was segmented into smaller excerpts (i.e. moves) using the procedure described in chapter 2.
3. Each move was then coded using the coding scheme (Table 5.2) to identify the elements of the semantic space.
4. Using a computer program, the concepts used in each design move were identified and a document-term matrix was created based on the frequency of concepts in each excerpt.
5. A graph (G) was constructed based on the document-term matrix in which nodes are the elements in the set of concepts (C) and edges between the nodes are shaped and weighted based on the total number of times they co-occur in each excerpt.
6. To extract the frame graph at the t_{th} excerpt of the design process, the first t rows of the document-term matrix were considered.

Coding Scheme	Description
Actors	These are entities named by designers in the situation. Following the principle of symmetry in Actor-Network theory, no distinction is made between human or non-human actors.
Attributes	Visual, physical or categorical properties of an actor. These properties can be described as independent of other actors.
Actions	These are what an actor performs using the affordances of other actors. Without actions, actors are merely a collection of possibilities.
Affordance	The concept of affordance is adopted from ecological psychology and specifically the work of Gibson. For Gibson affordances are the action possibilities offered by an environment to humans. It is important to note that affordance is defined relative to the actor and environments; artifacts offer different affordances to different actors. Agency is shared through the affordances offered by actors.

Table 5.2. Coding scheme for the analysis of design moves

Divergence-Convergence Metrics

Each design move adds one or more new edges to the graph or adds weight to the existing edges. In this sense, design moves can reconfigure the graph links in four ways:

1. Exploration (E_t): With the introduction of new nodes to the graph, new edges emerge. If L is an edge between nodes v_1 and v_2 in the graph G_t, then it is an exploration edge(E) if nodes v_1 and v_2 don't exist in the graph G_{t-1}. The exploration value of a move was calculated by counting the total number of exploration edges for that design move.

2. Integration (I_t): If L is an edge between nodes v_1 and v_2 in the graph G_t, then it is an integration edge(I) if one and only one of the two nodes v_1 or v_2 doesn't exist in the graph G_{t-1}. The integration value of a move was calculated by counting the total number of integration edges for that design move.

3. Densification (D_t): If L is an edge between nodes v_1 and v_2 in the graph G_t, then it is a densification edge(D) if nodes v_1 or v_2 exist in the graph G_{t-1}but Ldoesn't exist in the graph G_{t-1}. The densification value of a move was calculated by counting the total number of densification edges for that design move.

4. Repetition (R_t): If L is an edge between nodes v_1 and v_2 in the graph G_t, then it is a densification edge(R) if Lexists in the graph G_{t-1}but the weight of the edge L in the graph $G_t$is equal to the weight of the edge Lin the graph G_{t-1}+ 1. The repetition value of a move was calculated by counting the total number of repetition edges for that design move.

After calculating all four values for each design move, it can be represented by a vector of four dimensions:

$$M_t = [E_t, I_t, D_t, R_t]$$

While exploration and integration represent the expansion of the graph, densification, and repetition display thinking within the existing elements. This conception is aligned with the notions of convergence and divergence as states of focused and defocused attention (Gabora, 2010). While the former facilitates analytical thinking by limiting the attention to the existing elements within the context, the latter looks for new possibilities by expanding the scope of attention. As Goldschmidt (2016, p. 120) elaborates "focused attention is paid to what is already there" while "defocused attention allows the attention to wander, to imagine what is not yet there, what may be possible". We propose that exploration and integration display divergent thinking while densification and reiteration indicate convergent thinking.

Divergent thinking defocuses attention to facilitate processing more aspects of a situation and activating a larger set of properties (Gabora, 2018). This state of defocused attention allows new ideas or problem situations to emerge during the ideation process. Generating new ideas or coming up with new frames entails naming elements of the situation or retrieving concepts from memory. These new concepts are presented using new words that expand the semantic space of the design process. As new elements are added to the semantic space, they shape links with the existing elements and also with one another. In our dynamic semantic network model, divergent thinking manifests itself by increasing the network size and expanding its boundaries.

In contrast, convergent thinking limits and focuses the scope of attention to existing items and their relationships (Gabora, 2010). Focused attention on the context allows the designers to evaluate and analyze the problem and solutions. In the semantic network structure, convergence is reflected in the exploration of connections between the existing nodes. In this sense, densification and reiteration are convergent as they focus on the existing elements of the semantic network.

Influence Metrics

In addition to the four above-mentioned measures for evaluating the divergence or convergence of a move, we defined another measure to evaluate the influence of each design move on the lexicon used in the design conversation. Each design move introduces a set of new concepts (actors, actions, attributes, and affordances) to the existing lexicon of concepts used in building the design situation. However, not all the introduced concepts have the same impact on the direction of the ideas generated in the design process. While some moves introduce concepts that become central to the development of ideas in the design process, other moves are ignored after they have been proposed. To measure the influence of concepts and connection in design moves, we used the HITS (Hyperlink Induced Topic Search) algorithm. HITS was developed by Kleinberg (1999) as an algorithm to rank web pages based on their measure of "authority" and later applied by Mihalcea (2004) to text summarization. To rank web pages, HITS assigns an authority score (based on the number of incoming links) and a hub score (based on the number of outgoing links) to each web page. To apply HITS to text analysis, a network should be constructed with text segments as nodes and connections between text segments as edges. Edges between these nodes are weighted based on the number of connections between the two text segments. The key point here is the way the connection between two text segments is defined. To measure the influence of a design move on the design lexicon, we make a directed edge from design move x (represented by node v_x) and design move x+n (represented by design move v_{x+n}) if:

- Node v_x includes a new concept (c) which has not been introduced in any previous design moves.
- Concept C has been repeated in the design move v_{x+n}.

The weight of the edge between the two vectors is defined by the total number of concepts that connect two nodes. After the network is constructed, the HITS algorithm can be used to analyze the *hub value* for each node.

Results

Our analysis was initiated by evaluating the relationship between the team ideation performance and the ratio of divergent moves to all moves in the ideation sessions. The performance of each team was measured by counting the number of ideas generated during their design session. The focus was on the quantity of generated ideas since the main purpose of the ideation session was to generate as many ideas as possible. Designers were asked to list their design ideas at the end of each design session. Similar ideas in each session were combined to avoid redundancy. In total 89 design ideas were generated by 16 teams (μ = 5.56, max = 9, min 3).

Divergence value (d) was calculated by subtracting the convergence metrics (densification and reiteration) from divergent metrics (exploration and integration) and was normalized by dividing it by the total number of moves.

$$d_t = \frac{E_t + I_t}{E_t + I_t + D_t + R_t} - \left(\frac{D_t + R_t}{E_t + I_t + D_t + R_t}\right)$$

A move is divergent if $d_t > 0$ and convergent if $d_t \leq 0$. Table 5.3 displays the ratio of divergent and convergent moves as well as the number of ideas generated for all design sessions.

On average, sessions have a balanced ratio between divergent and convergent moves (μ = % 51.14, σ= % 9.48) and 8 out of 16 sessions had more divergent moves than convergent ones.

The ratio of divergent moves to all moves is positively correlated with the number of ideas generated in a session (r^2 = .61, p < .01). Designers in the ideation sessions with the highest percentage of divergent moves (12, 10, 11) have generated a high number of ideas (n ≥ 7). In contrast design sessions with the highest percentage of convergent moves (1, 5, 15) have generated five or fewer ideas. Results confirm the previous findings that divergent thinking is central to generating new ideas during the ideation phase of the design process.

Session index	Divergence (%)	Convergence (%)	Count of Ideas
12	65.45	34.55	7
10	58.65	41.35	9
11	56.91	43.09	8
7	56.45	43.55	6
6	54.12	45.88	7
14	53.73	46.27	5
13	53.41	46.59	3
3	52.58	47.42	6
2	49.40	50.6	4
8	47.83	52.17	6
9	46.43	53.57	5
4	41.67	58.33	7
16	40.34	59.66	4
5	36.67	63.33	5
15	34.43	65.57	3
1	31.71	68.29	4
Average	48.85	51.14	5.56

Table 5.3. The ratio of convergent and divergent moves and the number of generated ideas

Temporal Trends

Figure 5. shows the d-value of moves plotted over the move index axis for all sessions. To facilitate the comparison between different sessions, values have been averaged in a window of five design moves. The temporal analysis shows a cyclic pattern shifting between divergent and convergent moves. This constant shift between the convergent and divergent allows the designers to continue the flow of ideas by simultaneously expanding and exploring the design space. However, as Cross (2008) suggests, while the design process is constantly shifting between the two modes, overall, it's convergent. Our model reflects this convergent direction with the negative trend of d-values over the course of the design process. Table 5.4 shows the results of the regression analysis of the d-value over the move index for all design sessions. Except for sessions 1 and 15, all design sessions show a statistically significant drop ($p < 0.05$) in d-value over the course of the design process. Design starts with a divergent episode which marks the initial exploration of the problem. As design moves forward, these divergent episodes are replaced by convergent ones that explore the existing elements.

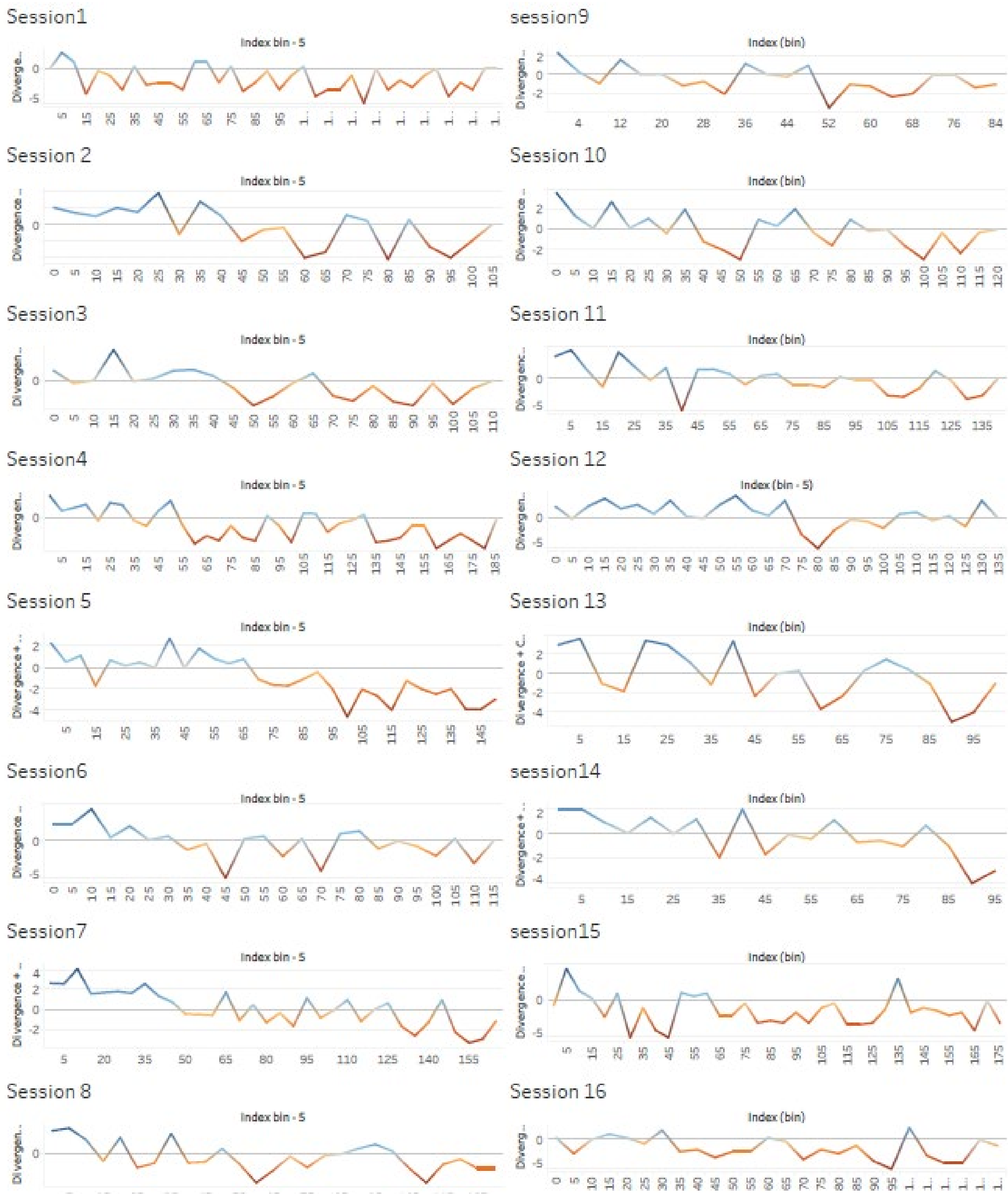

Figure 5.3. d-values plotted over the move index

Initial divergent episodes are longer in high-performance design sessions compared to low-performance sessions. In contrast, convergent episodes that show up later in the process are longer in low-performing sessions compared to high-performing sessions. Session 1 presents two examples of these extended episodes of convergence. Looking at the design protocols reveals that during these episodes, designers got fixated on specific attributes and actors. For instance, during the moves [47-60] designers extensively discussed the situation of parking lots around the campus and the number of blue light phones in different parking structures. During the next extended convergent episode [97-137], designers spent 40 moves discussing whether *children* should be considered as one of the users in the design of the blue light phone. While these discussions can be important in the overall design process, they stagnate the flow of ideas in an ideation session. A similarly fixated episode [40-59] can be identified in ideation session 15 during which designers discuss the acceptability of increasing the number of blue light phones as a solution based on the brief.

Session Index	α	$p-value$	R^2
1	-40.11	0.13	0.06
2	-42.46	0.002	0.37
3	-53.30	0.004	0.32
4	-84.69	0.0005	0.36
5	-89.57	0.0000	0.65
6	-39.71	0.019	0.22
7	-105.99	0.000	-0.60
8	-52.03	0.002	-0.31
9	-36.13	0.005	0.32
10	-52.88	0.008	0.26
11	-55.30	0.001	0.32
12	-39.45	0.04	0.14

13	-35.62	0.001	0.42
14	-53.33	0.0006	0.48
15	-29.69	0.15	0.06
16	-61.81	0.001	0.35

Table 5.4. The regression results for divergence values in the 16 design sessions

Individual Designers Role in Divergent Moves

Next, we looked at the differences in the contributions of designers to the generation of divergent moves. Table 5.5 shows the proportion of divergent moves carried out by designers in each design session and the discrepancies between the role of designers in creating divergent moves ranked by the ratio of divergent moves in the design session. The divergence ratio of each designer was calculated by dividing the number of divergent moves generated to the total number of moves generated by that designer. Sessions with a higher percentage of divergent moves (10, 11, 12) also show a higher discrepancy between the percentage of divergent moves generated by designers. Both designers in these sessions have a highly divergent style in these sessions. This similarity between the styles of designers can be observed in the design sessions with high-convergence values as both designers have highly convergent styles. The difference between divergence ratios is higher in the design sessions that are moderately-divergent or moderately convergent.

Session Index	Designer 1			Designer 2			Designer 1 Style	Designer 2 Style
	Divergent Moves %	Convergent Moves %	Divergence Ratio	Divergent Moves %	Convergent Moves %	Divergence Ratio		
12	39.13%	20.00%	66.18%	24.35%	16.52%	59.58%	**divergent**	**divergent**
10	33.00%	21.00%	61.11%	24.00%	22.00%	52.17%	**divergent**	**divergent**
11	41.38%	35.34%	53.94%	13.79%	9.48%	59.26%	**divergent**	**divergent**
7	30.40%	27.20%	52.78%	16.00%	26.40%	37.74%	**divergent**	**convergent**
6	30.00%	26.25%	53.33%	22.50%	21.25%	51.43%	**divergent**	**divergent**
14	30.16%	19.05%	61.29%	23.81%	26.98%	46.88%	**divergent**	**convergent**
13	32.95%	21.59%	60.41%	20.45%	25.00%	44.99%	**divergent**	**convergent**
3	14.29%	38.78%	26.93%	20.41%	26.53%	43.48%	**convergent**	**convergent**
2	25.00%	23.75%	51.28%	25.00%	26.25%	48.78%	**divergent**	**convergent**
8	28.26%	29.35%	49.05%	19.57%	22.83%	46.16%	**convergent**	**convergent**
9	28.85%	25.00%	53.57%	17.31%	28.85%	37.50%	**divergent**	**convergent**
4	23.48%	40.15%	36.90%	18.18%	18.18%	50.00%	**convergent**	**divergent**
16	15.04%	25.66%	36.95%	24.78%	34.51%	41.79%	**convergent**	**convergent**
5	16.10%	38.98%	29.23%	15.25%	29.66%	33.96%	**convergent**	**convergent**
15	16.52%	34.78%	32.20%	16.52%	32.17%	33.93%	**convergent**	**convergent**
1	20.34%	41.53%	0.33	9.32%	28.81%	0.24	**convergent**	**convergent**

Table 5.5. The ratio of each designer's divergent and convergent moves

Influence Analysis

Earlier in this chapter, we discussed that in addition to identifying divergent and convergent moves, constructed semantic networks can be used to identify the *hub value* of each design move. Hub value is calculated using the HITS algorithm which relies on the connection between moves as described in the methods section. This value represents how much the concepts introduced by that move have influenced the lexicon utilized in the following design moves. We expected this measure to enable us to identify design moves that are key in shaping the design discourse. We hypothesize that moves with a high hub value to be key moves in the design process.

In this section, this idea is briefly explored using one of the design sessions (#13). This design session consists of 118 moves. Figure 5.4 shows the d-value and hub values of these moves plotted against each other. A design move has a positive d-value when it introduces new concepts to the network. However, these concepts may or may not influence the lexicon used for framing the problem or generating ideas.

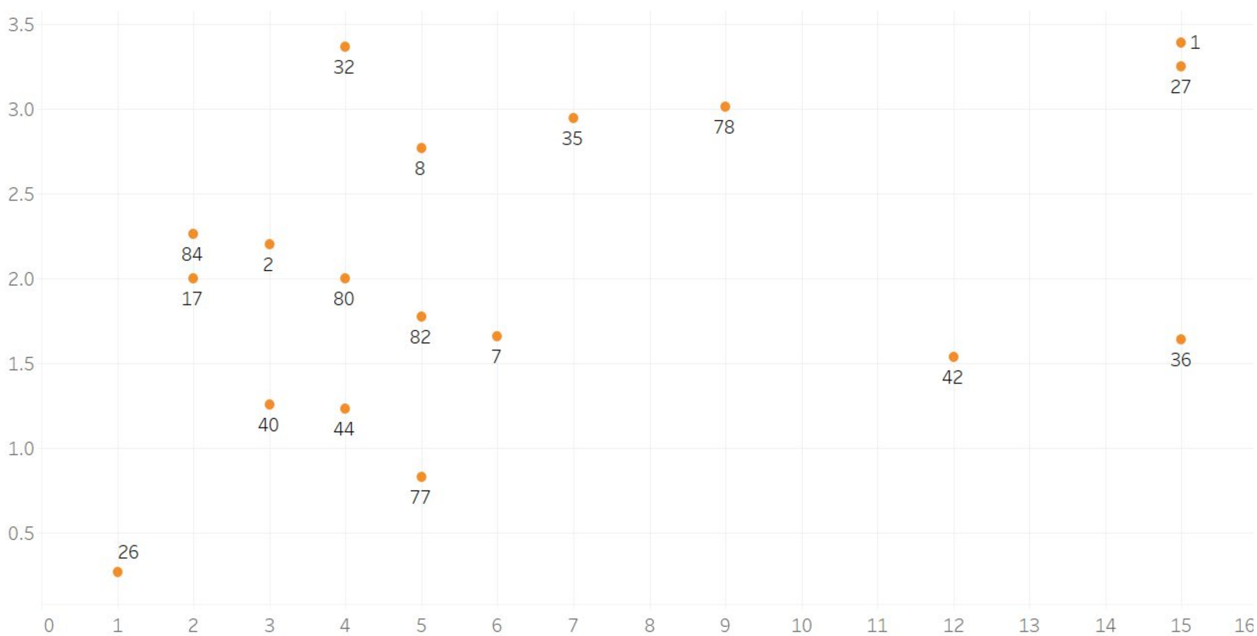

Figure 5.4. - Moves with positive hub value and d-values

The excerpts referenced in the analysis below are listed in table 5.6. Move 1 is an example of a key move that shows both high hub value (3.39) and d-value (15). This design move introduces several key concepts to the process (*emergency system, blue light phone, user*) which gives an initial framing of the problem. As expected, these actors become very central in the design discussions and are referenced frequently. Move 27 is another one that shows both high d-value (15) and hub value (3.4). This move proposes the first major solution to the problem ("*blue LED runners on the ground that extend onto the paths that lead to the light*") which introduces several new actors and actions and is developed and explored extensively in the following design moves.

Design moves can have high hub value without having a high d-value similar to design move 1. A design move might have a small but positive d-value in which the introduced concepts become highly influential in moving the process forward. For instance, design move 2 has a relatively small d-value (3), however, it shows a high hub value (2.3). This contrast is because move 2 introduces the *visibility* attribute which becomes a key concept in generating ideas. Similarly, the design moves [7-8] brings up two new concepts (being aware of and being able to locate blue light phones) that, similar to move 2, turn into very central concepts in the design discussions. Instead, it is the move 78 (d-value = 9, hub value = 3.1) that presents a new direction for the design (scaring the attacker) which is explored in the moves [80-88].

A high d-value doesn't necessarily translate to high influence as these new concepts might not be pursued for the rest of the design process. These ideas or frames may bring multiple concepts that are abandoned for the rest of the process. For instance, moves 3-7 introduce multiple new concepts similar to design moves 1 and 2. However, none of these concepts are repeated in the rest of the design conversations. As a result, these moves show a high d-value but a hub value of 0. In the same way, design move 18 presents an interesting case with a high d-value (14) and a hub value of 0. The new concepts and links presented in this move (e.g. removing phone cradle, contacting police office) are never used later in the design process.

Move Index	Excerpt
1	Our goal is to improve the emergency system on campus to have people easily find the blue light phone in cases of emergency.
2	I am from an architecture background. In my point of view, the key point is to make it more visible and accessible.
7	I agree. They listed a lot of stats on this paper, the ones that jumped out at me were not so much the awareness like it said 92% of the students are aware of the system. Thirty-two of the 35 who needed it knew it was there.
8	The more troubling statistics were: the fact that only 40% can locate and 8% know where the closest is.
18	Yeah, I think here they mentioned when the telephone receiver is removed from the cradle, then it just calls to the police office, right? So it contacts the closest police officer. And then they'll come.
27	The first thing that came to my mind is the idea of blue LED runners on the ground that extend onto the paths that lead to the light. So, in this case of a picture along the sidewalk, there would be blue runners maybe a couple, maybe 20 feet out in every direction.
32	Another idea is blue arrows on the ground to point to where the nearest blue light is.
35	So I thought if the lampposts have blue arrows on them that point to where the nearest blue light phone is, that could also help people find them. Because there are already a lot of lamp posts around anyway.
75	And also, a lot of times, what I've heard of these systems being used it's ... someone's kind of following you at night and you don't want them to know that you know, so you want to be able to very discreetly get to an emergency phone.
78	Do you think for the people who are in an emergency situation and they are running: is there a way that the design could scare the attackers?

Table 5.6. The excerpt from Design Session 13

Discussion

The creative process involves a constant shift between divergent and convergent thinking. These shifts involve focusing and defocusing the designer's attention in the context (Gabora, 2010). In the focused mode, attention is paid to already existing elements and in the defocused mode, attention is widened to explore new elements. In this chapter, we presented a new approach for modeling divergent (defocused) and convergent (focused) thinking. This approach utilizes the shifts in the sequential semantic networks constructed from the conversations between designers to identify divergent and convergent moves in the design process. We defined divergence as the introduction of new connections to the network between two new nodes (concepts) or a new node and an existing one. Convergence, on the other hand, connects the existing nodes or reinforces the connections present in the network.

This model was used to analyze the temporal patterns of divergence and convergence in 16 ideation session of graduate students from different design disciplines. Results were aligned with the existing literature on divergent and convergent thinking in design. The analysis illustrates that design goes through multiple cycles of divergence and convergence. However, the overall trend of the ideation process is convergent.

We also showed that the ratio of divergent and convergent thinking varies substantially across design teams and could be an indicator of team performance. Designers in highly divergent sessions generated more ideas compared to the ones in highly convergent sessions. We also looked at the individual designers' contribution to the generation of divergent and convergent moves in the process. Discrepancies in the contribution of designers to divergent moves varied widely among design sessions. While in highly divergent and highly convergent sessions, designers shared the same cognitive style, designers showed different styles in sessions with a more balanced divergence to convergence ratio.

The potential of this model was examined for identifying the moves that have introduced the most influential concepts to the conversation. These moves bring new connections to the networks that have been referenced frequently in the rest of the design process. We used a design session to show how using the HITS algorithm these highly influential moves can be identified.

The model presented in this chapter enables a micro-level analysis of the design process. What differentiates the model from existing models is that it connects the process-oriented and content-oriented models of the design process. Processes are derived from changes in the semantic network. The model at the same time enables visualizing the design content and process as a network structure.

Chapter 6 Conclusion

In the past few years, a new appreciation has emerged for the designers' ability to imagine creative solutions. Public and private organizations are increasingly turning to designers to bring a fresh perspective to the challenges they are facing. With the increasing involvement of designers in large-scale and intricate problems, the need to develop systematic approaches to design and their deployment in both design education and practice becomes more evident. Creating methods that function successfully within design environments requires a thorough understanding of problem-solving approaches in design. In recent years, a growing number of studies have addressed this question by investigating designers' working practices in the lab or the field.

One of the most influential concepts in studying the design process is the constructivist notion of framing (Schön, 1983). This model suggests that the core activity in the design process is constructing a frame: a perspective or a point of view that allows the designers to tackle a problem in a vague and indefinite design situation. Empirical studies, in general, and verbal protocol studies in specific, have utilized the concept of framing as a lens to analyze the design process. While the frame's theory has been central in these studies, its formal definition and description remain unclear.

This dissertation contributes to this body of research by proposing two models for systematically describing design frames. These models can be used to make explicit the frames constructed during the design process and accurately describe their development throughout the design process. To build these models, we drew upon the cognitivist tradition and, in specific, the framework of knowledge representation proposed by Minsky (2007). This framework organizes modes of knowledge representation on a hierarchical continuum between semantic representation on the top and neurobiological systems at the bottom. Building upon two language-based representation modes from Minsky's framework (stories and semantic networks), the models discussed in this dissertation facilitate a more accurate description of the frames and an analysis of the design process by tracking the shifts in their content and structure.

Models

Stories enable humans to construct and communicate their understanding of an existing condition and their imagination of how things can be. The ability to tell stories has been described as the skill that distinguishes humans from other animals. Minsky's framework (2007) describes a story as "a sequence of events in time." Previous studies have explored the possibilities of storytelling as a framework for the analysis of the design process (e.g., Lloyd & Oak, 2018). The model presented in this dissertation distinguishes itself from the existing ones by making a distinction between a story and a narrative. A story is a descriptive tool that offers the designer's understanding of a situation or its imagined future. However, a narrative is a system of stories that defines their relationships and provides a diagnosis of the situation (Corman, 2013). Designers construct coherent narratives around stories, which then enable them to imagine new situations. Narratives are frames that guide designers' search for new stories and structure their understanding of the existing ones. New stories can be attached to a narrative, and existing ones can be detached without disrupting its core structure. Therefore, design can be analyzed as constructing narratives that encompass stories and create overarching themes throughout the design process.

On the other hand, a semantic network represents a situation as a series of concepts and their connections. However, the question arises as to what elements to extract from the verbal communications between designers to describe their understanding of design as a network structure? To answer this question, we adopted four concepts (actors, actions, affordances, and attributes) from the actor-network theory (Akrich, 1992; Yaneva, 2009) that provides a framework for extracting concepts from verbal communications. This framework was used to analyze design protocols. Extracted concepts constitute the nodes in the network, and they were connected with a link between them if they have been used in the same context. As designers move forward in the design process, new elements and connections are added to the network. The advantage of this model over existing network representations (e.g., mental models) is that it enables us to study the design process by tracking shifts in the structure and content of the frames constructed by designers.

Key Questions and Answers

These models were utilized in three verbal protocol studies to investigate different aspects of framing in design. Protocol analysis is an observational technique that aims to understand the design process by analyzing the conversation between designers. Two approaches are often taken for protocol analysis of the design process: a content-oriented approach which focuses on “what designers look for, see, do, and possibly think” (Dorst & Dijkhuis, 1995), and a process-oriented approach which focuses on the activities of designers and underlying processes. In these studies, we explored strategies for managing the multiplicity of frames (chapter 2), reframing processes (chapter 3), and divergent and convergent patterns (chapter 4) during the design process.

The third chapter starts with the proposition that designers deal with the ambiguity of the design situation by constructing a multiplicity of frames. This chapter aims to investigate the patterns by which designers generate these frames and explore their potentials throughout the design process. The narrative model was used to build a coding scheme to extract the frames from the design protocol and map their temporal distribution in each session. Two patterns of frame generation (concentrated and diffused) and frame exploration (parallel and serial) were identified. Some design teams combined the two strategies: generating multiple frames early in the process and generating new frames as they moved towards a solution. Design teams that advance frames simultaneously (parallel strategy) created a higher number of frames compared to those who explore frames one by one (serial strategy).

In chapter 4, we put the narrative model into use to identify the processes that lead the designer to discard a frame and adopt a new one i.e. reframe. The existing literature on reframing highlights the significance of moments during the design process. The current frame is challenged by a crisis in understanding the design situation or the surprise of a new opportunity. However, the question that begs to be answered is what leads to these moments of crisis? We investigated this question by analyzing two reframing episodes using the narrative model. Each reframing episode started with the generation of a frame and concluded with the rejection of the frame and the creation of a new one. In both episodes, moments of crisis were the culmination of small reflections that challenged the narrative and ultimately led to a reflection-on-frame and rejection. In both episodes, only a few reflections directly targeted the narrative, and designers mainly reflected on solutions. These reflections can challenge the narrative in two ways. First, reflecting on solutions led designers to discover new stories that were not originally considered in the narrative. The accumulation of these stories directed the designers to modify the narrative to adapt to new stories. Second, designers reflected on the effectiveness of the solutions generated within the narrative. Therefore, the process of reflection can challenge the narrative by evaluating the narrative's capacity to explain new stories and create effective solutions. If designers conclude that new stories do not fit within the given narrative, and the narrative doesn't enable generating effective and novel solutions, the narrative might be temporarily or permanently abandoned in the search for a new one.

Chapters 3 and 4 showed the narrative model's capacity in describing different aspects of the framing process. Chapter 5 explored the potential of the network model for describing the micro-level actions in design. The model discussed in this chapter represents design as a process of constructing a network during which new concepts (nodes) and connections (edges) are being added to the network. Similar to chapter 3, processes were defined by changes in the content and structure of frames. Moves that generated new nodes and connections were identified as divergent, while the ones that reinforced existing nodes and links were marked as convergent. We obtained a profile of the design sessions' convergence and divergence moves throughout the design process. Design sessions' analysis confirmed the recent developments in dual-process theory in which designers continually switch between divergent and convergent modes. The results also showed that design sessions with a higher percentage of divergent moves generated more ideas compared to convergent sessions. Also, design sessions with the lowest number of generated ideas showed extended periods of convergence.

The results of this dissertation are subject to limitations since empirical studies were conducted with graduate students. Although most participants had some experience in a professional setting, the results cannot be immediately generalized to a professional design setting with experienced practitioners. Besides, design sessions were conducted in a lab situation that is less complicated relative to the real-world design environment with multiple stakeholders who engage in a situation over extended periods. In such situations, framing involves numerous phases of negotiation and refinement between stakeholders with different values. The lab setting also limited the designers' ability to collect and synthesize information, as they only had access to the design brief. Furthermore, our analysis was limited to ideation sessions, while the design process involves multiple cycles of ideation, making, and evaluation.

Future studies are needed to address these issues. Design researchers can utilize the models introduced in this dissertation to study design processes as they play out in design practices with real-world problems. The narrative model is specifically well-suited for analyzing the clashing frames in design practices and the way designers manage this multiplicity of frames. Such studies can also address the ways in which information-gathering activities in the real-word setting impact the framing process. Furthermore, the framing process should be analyzed over the full life cycle of a design process and not merely within the ideation phase.

Contributions and Recommendations

Contributions of this dissertation are theoretical and practical. This research opens up new paths for future research on framing in design and inform design educators and practitioners by offering practices to stimulate creativity and enhance problem-solving.

The models presented in this work offer new ways to design researchers for analyzing the design process. First, these models provide formal ways to identify and describe frames in the design process. The two models offer distinct, yet connected, perspectives into the design process. While the narrative model looks at the design situation through a cause and effect lens animated by actors and actions, the network approach models the situation as a set of relations between objects and actors. Through the frameworks and methodologies presented in the second chapter, researchers can extract design frames from conversations between designers. While this work mainly relies on the data collected from a controlled design session, the methodology can be utilized in analyzing communications of real-world design practices. Especially with the use of automated text analysis methods, design researchers can use data sources such as emails, instant messages, and online meeting transcripts for running such analyses. These models also make it possible for design researchers to have a more unified vision when describing and analyzing frames.

Second, these models enable a temporal analysis of the design process by mapping frames and tracking their changes over time. Network-based techniques for visualizing the design space (e.g., mind mapping and concept mapping) are often conducted before the design process begins. However, the network approach presented in this dissertation relies on mapping the design space as constructed through the conversations between the designers. The network is the outcome of the negotiations during the design process itself and not an isolated phase. Similarly, the narrative model presents a framework that allows mapping the design conversations into a series of temporally arranged narratives. This model adds a temporal dimension to the network, enabling us to study the structure of networks and their shifts over time. In chapter 4, this model was used to characterize design moves based on their impact on network edges. Future research can utilize these frameworks to trace the shifts in the design space quantitatively and qualitatively. This temporal mapping of frames can be applied to the study of bimodal thinking processes and specifically divergent and convergent processes in design. On the other hand, these models can be use d in future research to study reframing process in design through the study of interactions between meta (network and narratives) and component-level (concepts and stories). Future studies can use this model to study the relationship between design outcomes or the cognitive style of designers and temporal patterns of the shift in network analysis metrics, e.g., centrality and connectivity.

Besides their theoretical implications for future research, the models introduced in this study can be utilized as educational tools to enhance collaboration and creativity in design students by enabling them to make their frames explicit. As discussed earlier, frames are devices that shape the meaning of a situation and structure the process of problem and idea generation in design. The narrative model provides a structure for designers to make these implicit frames explicit, communicate them to other designers, and coordinate their efforts. Students can learn to use the narrative model to improve their communication skills and resolve conflicts during the collaborative process. By making their frames explicit, students can share frames underlying their assumptions and engage in a dialog. On the other hand, students can broaden their perspectives and think about the design situation in new ways. Hence, these models have the potential to stimulate creativity and overcome fixation by mapping the assumptions underlying design ideas.

When a student is fixated on an ineffective design solution, the studio instructor can suggest a narrative mapping exercise to encourage the student to question some elements of his/her frame and think in new ways. Similar approaches can be utilized outside the educational settings by real-world designers when facing a roadblock during the design process. To use narrative as a lens to reflect on frames, the student needs to question their assumptions by asking reflective questions such as: What is my narrative of the situation? What are the stories that support or reject my narrative? How do my solutions respond to this narrative? Does my solution solve the problem posed by the narrative? If not, what are the challenges that remain? Does my solution cause new problems or shed light on new issues that are ignored in the narrative? Asking such reflective questions makes it possible to go beyond the initial framing and open the way for further options.

However, it should be noted that this reflective approach has been criticized in past years by those who argue that designers should aspire to communicate in ways that maximize idea generation during an ideation session. The judgment of ideas should be deferred until the session is over. While the results of the analysis in chapter 4 also confirms that extended periods of reflection during brainstorming can stagnate the flow of ideas, this study and other studies have found that reflection is central to the generation of creative ideas during brainstorming (Cardoso et al., 2016; Norman & Verganti, 2019). As shown in chapter 3, reflections set the stage for the advent of new frames by challenging the effectiveness and coherence of existing frames. Reflecting on ideas during the design process can lead to the emergence of new frames and ideas that would not have emerged if designers merely build on top of each other's ideas. Future research should examine the brainstorming strategies that can maximize the positive impact of reflections in improving the quality of ideas and the generation of new frames and minimize the possibility of fixation and obstructing the flow of ideas. Therefore, to stimulate reframing in ideation and brainstorming sessions, reflections on solutions should be encouraged; however, reflections should not block the flow of ideation.

On the other hand, the network model can be used to evaluate and augment the collective design process. The network approach gives us a window into the design process through a semi-automated analysis of the conversations between designers. Organizations can apply this approach to identify the cognitive styles of team members and utilize them in setting up more effective design teams. The method introduced in this dissertation doesn’t enable real-time analysis of the design process since it requires some human input for coding and analysis. However, it’s possible to fully automate the process in the future through more advanced text analytics and develop digital platforms for real-time network visualization of the conversations between designers during the ideation process. This network visualization can make the constructed frames explicit in real-time without disrupting the design process’s flow and enables designers to create a shared image of the situation. In addition to visualizing the design content, the approaches described in this dissertation enable tracking divergence and convergence moves during the design process. Tracking these processes makes it possible for design teams and managers to identify the fixation points in ideation or brainstorming sessions and intervene to get the process back on track.

As boundaries between design disciplines are fading away, there is an increasing need for understanding the epistemological structures that enable designers to work effectively on design problems. Designers today should be equipped with techniques and knowledge that make them ready for dealing with complex and networked problems of the real world. Design research can play a role in preparing designers by building such techniques and methods based on a deep understanding of the design process.

Appendices

Appendix A Design Session Problem Brief

Department of Public Safety at a Midwestern public university is always looking for ways to improve the safety of the campus environment. The department has recently installed emergency phones (also known as blue light phones) at several locations on campus. These stands are located at several locations around the campus in order to provide quick access to police officers. In the current blue light phone system, DPSS Communications Center is alerted if a call is made. An officer is sent to the location of the telephone when the telephone receiver is removed from the cradle. Dialing or conversation is not required for the alert and the dispatch of an officer. The current system has accelerated access to the Department. With the new system in place, the time to report an incident to the department has dropped by 4 minutes.

Despite the positive impact of the blue light telephones, most students have difficulty with finding the blue light telephones in the cases of emergency. A recent survey of 142 students across the campus shows that while 92% of the students are aware of the system, only 40% can locate one of the blue light telephones and only 8% know their closest blue line telephones. Also, during the month of November, only 5 out of 35 students who required emergency access to police have been able to find a blue light phone close by, despite the fact that 32 out of 35 students were aware of the system.

Department of public safety has recently announced a call for ideas to improve the emergency system on campus. The proposed ideas should help people to easily find the blue light phones in the cases of emergency. Ideas are not limited in their choice of the technology, implementation, and scope of the solution. In the first round of this project, jurors are looking for innovative yet practical ideas.

Figure A.1. Image of a Blue Light Phone Pole presented to participants during the design session

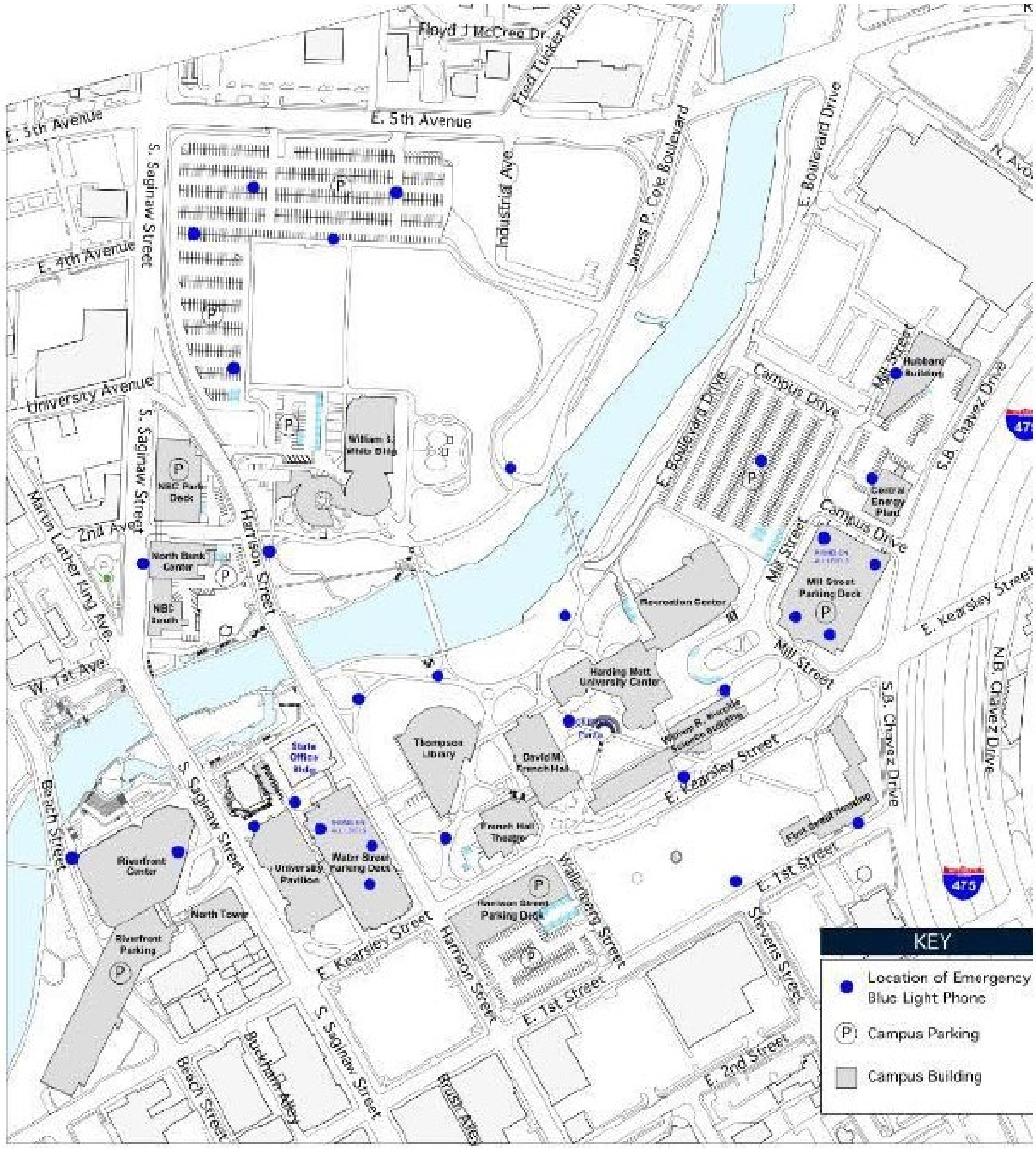

Figure A.2. Campus map presented to participants during the design session

Appendix B Frame Analysis of All Design Sessions

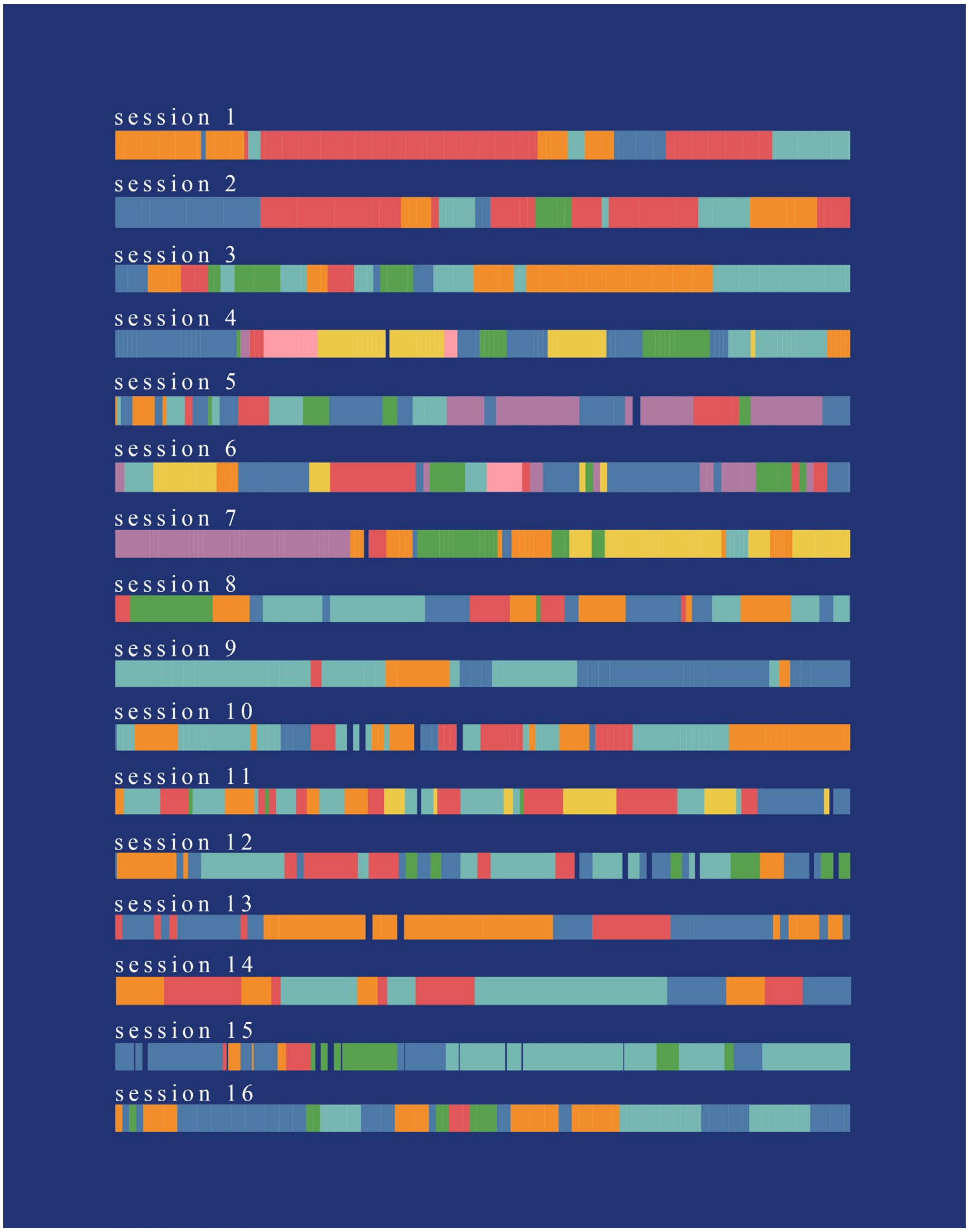

Figure B.1. Sequence of frames created in 16 design sessions

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