REFLECTIONSPACE: AN INTERACTIVE VISUALIZATION TOOL FOR SUPPORTING REFLECTION-ON-ACTION IN DESIGN

BY

MOUSHUMI SHARMIN

DISSERTATION

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Doctoral Committee:

Associate Professor Brian P. Bailey, Chair
Associate Professor Karrie G. Karahalios
Professor Michael Twidale
Associate Professor Eli Blevis, Indiana University

Abstract

Designers move forward by looking back at past experiences. Reflection is a central activity of creative design which allows designers to develop new insight into their designs, generate alternative solutions, and reframe the problem. Researchers have emphasized the positive impact of reflection on design outcomes - recognizing the effectiveness of reflection as a learning tool and suggesting that designers who adopt reflective practices acquire better understanding of their design processes. This dissertation examines novel ways to augment reflective practice through design process visualization.

The hypothesis of this dissertation is that a visual representation of design materials that captures and communicates the design process and context of design activity will better foster reflection-on-action. In support of this hypothesis, this dissertation makes three contributions to the field of human-computer interaction; (i) it reports results from three field studies of reflective practice and re-appropriation during the early phases of creative design; (ii) it describes the design and implementation of an interactive visualization tool supporting reflection-on-action; and (iii) it provides empirical evidence of the effectiveness of design process visualization for supporting reflection-on-action.

To investigate the benefits of reflection support tools for creative design, we developed ReflectionSpace, an interactive visualization tool supporting reflective activities. The key innovation in ReflectionSpace is that it maps existing design materials to appropriate design phases and contexts of use and places corresponding representations into a time- and activity-centric visualization that can be navigated at different levels of detail. Results from a laboratory study indicate that a visual representation of design process is preferred over a file-centric approach for supporting reflection-on-action. Our work provides empirical evidence that interactive visualization of design process benefits designers by supporting reflection-on-action and contributes lessons that can guide the design of a new generation of design support tools.

To my family

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Chapter 1

Introduction

1.1 Problem and Significance

Reflection-on-action is a critical component of creative design. It enables designers to evaluate their design process, learn from past successes and failures, and gain inspiration – which in turn can improve design efficiency and outcomes [1]. For example, a graphic designer may engage in a "self-evaluation" session after completing the design of a web site and ask whether the final design met client requirements, whether she pre-maturely committed to a prototype, or whether this project took longer than other web design projects that she worked on. Unlike reflection-in-action which enables in-the-moment thinking about design activity, reflection-on-action enables critical thinking about prior actions holistically [2]. While less frequent and more granular than reflection-in-action, reflection-on-action is equally important for improving design outcomes [3]. This motivated us to examine behavior related to reflection-on-action, build an interactive visualization tool that supports this behavior, and evaluate its impact on reflection for authentic design projects.

Existing artifacts play a vital role in creative design - designers utilize existing artifacts to formulate the design problem, generate ideas, and evaluate alternatives [4], [5], [6]. Studies confirm that designers often access prior episodes (experiences) when challenged with new problems [7]. Advances in computing technology empower designers to explore, collect, and store artifacts from a variety of sources, including their own prior projects and other designers' projects. However, these tools only provide access to specific artifacts, disregarding designer's needs to recall design process, stories, and context. To mitigate limitations of file-centric approaches to represent design process and context, designers try to map their process using folder organization, file naming, tagging, etc. Figure 1.1 presents one such representation typical of the mappings that designers develop. This graphic designer created a naming convention where project names start with a number to indicate project-priority (1 indicates highest priority),

"x" indicates project status (presence of 'x' indicates completion of idea generation), and highlight indicates an unmet dependency. While the project folder is aimed to reflect the status of the project, sub-folders are used to capture the design iterations (e.g., "round 1" contains all artifacts generated in the first iteration of the project). Prior work show that these types of naming schemes are quite common in practice [8],[9]. However, the problem is that these mappings are idiosyncratic, lose meaning over time, are easily forgotten, and not always adhered to. In addition, this text-centric representation makes it difficult to answer reflective questions such as which artifacts influenced the final design most, when did I commit to a particular design direction, and which design phase was the most challenging and required investing the most effort.

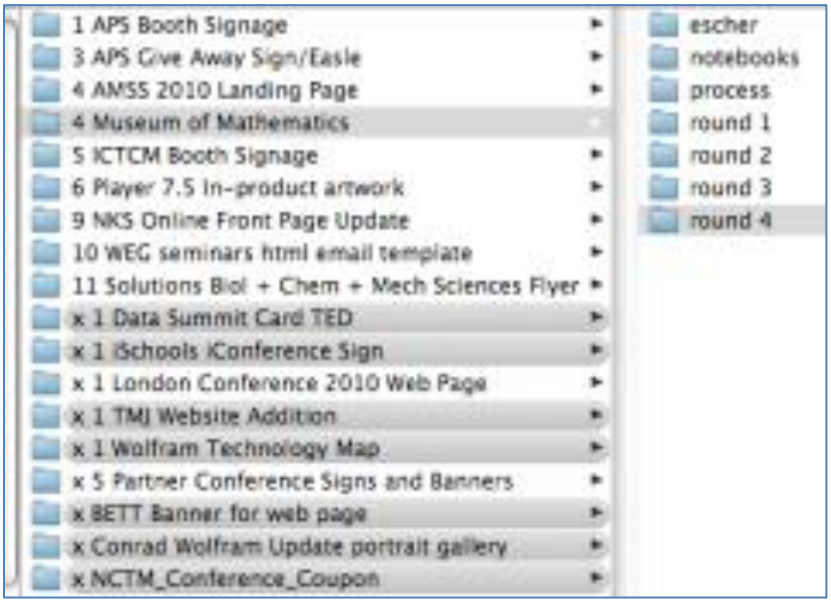


Figure 1.1: Folder structure used by a graphic designer. This structure is used to reflect project priority, status, and design process.

1.2 Existing Approaches

Prior knowledge is a critical resource for design, especially when designers are striving to generate new ideas for complex problems. This has spurred much research into systems that facilitate recalling past states, enable rapid access to prior artifacts, and supports reuse of similar solutions. Designers could attempt to use these reuse support systems to engage in reflection, however, none of them were designed to support activities related to reflection-on-action.

The most relevant thread of research to our work is systems that enable documenting and reflecting on the design process by creating spatial views of artifacts [9]. Systems also focus on facilitating reflection-in-action by supporting creation and analysis of alternative solutions [10],[11], capturing evolution history of artifacts [12], and supporting analysis and refinement of ongoing design tasks [13]. None of these prior systems has targeted activities associated with reflection-on-action, which is the focus of this dissertation. In addition, none of these systems have been shaped by understanding the reflective activities designers engage in practice.

Researchers have focused on creating repositories of prior cases (e.g. artifacts and descriptions) which can be efficiently represented, indexed, and retrieved [14]. Another area of focus was capturing the decisions and rationale relating to the construction of design artifacts [15], which can be traced to support redesign and maintenance efforts. Reuse of existing components and patterns is also a common practice in many engineering design domains. These systems primarily focus on the detailed design and implementation phases, when designers are seeking solutions to defined problems.

Many types of design support systems are available, but few, if any, have been widely adopted for creative design. We argue this is because such systems (case-based systems, design rationale systems, activity capture systems, etc.) do not adequately support the needs of designers' surrounding reflection-on-action as they have not targeted activities that designers want to perform, such as comparing the process of multiple design projects and estimating effort invested on ideation. This is due in part because designers' needs and activities are not yet well understood. This dissertation fills this gap by offering deeper understanding of designers' attitudes toward and practices of reappropriation and reflection. This dissertation also identifies activities related to reflection-*on*-action and contributes the design and implementation of a novel visualization tool that explicitly supports reflective activities.

1.3 Our Approach

Our solution addresses the problem of supporting reflection-on-action. Our work is inspired by Schön's conceptualization of reflection-on-action and extends it by identifying how the cognitive act of reflection translates into specific design activities in practice. By studying designers' reflection practice, we postulated that a visual representation of design artifacts that captures and communicates the design process and context of design activity would better foster

reflection-on-action. To validate our approach, we designed, implemented, and evaluated ReflectionSpace, an interactive visualization tool for supporting activities associated with reflection-on-action. Evaluation of ReflectionSpace with professional designers showed both qualitative and quantitative benefits of our approach [16].

There are several key innovations in ReflectionSpace. First, ReflectionSpace supports recalling design stories, understanding the flow of design, comparing different projects, estimating time invested, and discovering hidden patterns. Second, ReflectionSpace offers a time- and activity-centric visualization of design materials that can be navigated at different levels of detail. Third, ReflectionSpace uses file meta-data and naming conventions to map existing artifacts to appropriate design phases and contexts of use. Fourth, we also provided evidence of the effectiveness of process visualization in supporting reflection-on-action. Such visual representation of design process was preferred over a file-centric approach to support recalling the design process, comparing processes of different projects, estimating effort invested, and also identifying change in the design direction. Fifth, we also identified the key areas that would remove the barriers that hinder reappropriation. Effective representation of design process not only enables designers to explore artifacts but also reveals relationships between the artifacts in ways that are meaningful to the designer. Overall, lessons from our studies, implementation and evaluation all contribute to understanding and improving the practice of reflection-on-action. These include identifying questions triggering reflection, activities performed, and problems faced, all of which help shape the design of reflection support tools and open up many new directions for future research.

1.4 Motivating Example

In this section we discuss the challenges faced by designers surrounding reflection-on-action and how the use of ReflectionSpace mitigates those challenges using a hypothetical scenario adapted from a real design story.

Jen is a freelance product designer. Recently she is designing a college bag that targets urban teen population. She started the project by collecting information about the client, the target audience, existing products, and other products used by the target users. She started thinking about her past experience working for the same client, hoping to recall the client's preference and what worked and didn't work when working for this client. Failing to recall

details about her experience, Jen decided to take a closer look at all the materials pertaining to this past project to get an idea about her design process, rationale, and time requirement. However, the artifacts stored in the file system only helped her to access "what was created and delivered" without providing any details about what process she followed, how many concepts she generated and how she selected the final concept, how the prototype evolved, her rationale, and the effort invested in the different phases of this project. The only *useful* artifact Jen found was the "final.pdf" file that contained images of the artifacts from the different design phases. These images helped her recall that the final prototype was inspired by a Nikon camera case, but she had no idea how that design influenced the final product, when during her design she decided to follow this direction, or what the clients opinion was. She started to examine contents of different folders hoping that it will help her to answer her questions, but soon realized that artifacts alone offer little support for her needs.

Now consider the same scenario where Jen is using ReflectionSpace, an interactive visualization tool that offers a time- and activity-centric representation of her entire (electronic) design space. ReflectionSpace allows her to browse through artifacts by selecting the past project, explore artifacts at different levels of detail, examine artifacts based on context of creation and use, estimate effort invested in different types of design activity, and see the progression of the project in terms of activities performed. This system makes her activities and the surrounding design process visible, providing better support for understanding effort spent on the project overall or on any design phase. With this system, she can add free-form rationale with her artifacts, mark her favorite artifacts, and create stories referencing different types of artifacts. ReflectionSpace thus aids in answering many of the questions that Jen had but failed to remember using traditional file-centric systems.

To answer her questions, Jen first examined the summarized representation of the design activities to get a sense of the process utilized and time requirements for the different phases. She identified several points in the design that marked a change in her design focus. She decided to take a closer look at the artifacts created and accessed at these critical points. She discovered that one change in direction was brought by a communication between the client and her. She decided to examine the artifacts sent to her client prior to the discussion, the clients' feedback, and artifacts designed after the communication had occurred. She opened up the associated artifacts in their respective application windows and started examining those in detail. After

spending time looking at the various representations and interacting with the artifacts, Jen realized that unlike her recent projects, in this project, most of her effort went into the prototyping phase due to the large number of revisions created in response to feedback received from her client. To make her process more effective, Jen decided to communicate frequently with her client throughout the design process and she also made mental notes about the clients' preferences to avoid unexpected delays during this new project. She now felt better prepared for this new project.

The goal of this dissertation is to support designers like Jen who faces challenges in engaging in reflection-on-action by creating a novel interactive visualization system.

1.5 Contribution

This dissertation makes the following contributions:

i) ***Reports results from studies of reflective practices and reappropriation during early phases of creative design***

This thesis offers new understanding of designers' reappropriation behavior and activities and needs associated with reflection-on-action. To gain a deeper understanding of designers' attitudes and practices towards reflection, reappropriation, and communication, we conducted three studies - a contextual inquiry observing designers' work environment, semi-structured interviews gaining insight about reflection and reappropriation strategies utilized in practice, and an online survey collecting specific stories and anecdotes. We identified how the cognitive act of reflection translates into specific design activities in practice and provided a collection of the most frequent questions asked by designers while engaging in reflective activities. Results from these studies indicate that designers want to think holistically about prior design processes, estimate effort invested at different design phases, extract design "stories," compare projects in terms of design processes, revisit "successes" and "failures" and assess progression in the current design project. Our findings also indicate that engaging in reflection-on-action is typical and the traditional file-centric approach offers limited support for engaging in reflection. Details about these studies and the results are reported in chapters 3, 4, and 5.

ii) ***An interactive visualization tool for supporting reflection-on-action***

This dissertation contributes the design of ReflectionSpace, a novel interactive tool for supporting reflection-on-action through a visualization of design process. Our design is

motivated by designers' reflective practice and their needs surrounding reflection-on-action, and literature on design and creativity. The key innovation in ReflectionSpace is that it offers a time- and activity-centric visualization of the design process that aids designers engaging in reflective activities. ReflectionSpace uses file meta-data and naming conventions to map artifacts to the appropriate design phase and context of use. We provide details of the system design and implementation in chapter 6.

iii) ***Provides empirical evidence of the effectiveness of design process visualization for supporting reflection-on-action***

This dissertation contributes findings from a comparative study evaluating the efficacy of ReflectionSpace, an interactive design process visualization tool. Our work provides evidence of the effectiveness of design process visualization in supporting reflective activities through a lab study conducted with experienced designers using authentic design projects. Our findings show empirical benefits of this approach, and highlight some of the needs in supporting reflective activities that arise from the system with real users. ReflectionSpace aids activities associated with reflection-on-action and may inspire additional tools aimed at fostering reflection practice and creative design. We provide details of the system evaluation in chapter 7.

1.6 Scope

In this dissertation we focused on a subset of design domains, the creative design domains, including but not limited to graphic, Web, interaction, and industrial design. We chose these domains as reflection is considered a critical part of the creative design process. These domains are also less studied than engineering design domains in terms of knowledge reused. The domains studied are unique in the types of artifacts created (e.g., sketches rather than source code), but similar in that designers need to create artifacts, follow processes, and make design decisions. Our findings and implications thus complement study results in other design domains, e.g., [17], [18].

We focused on supporting activities associated with reflection-on-action, especially focusing on the early design stage. The type of information designers seek and the activities they perform at this stage is informal and ad-hoc and typically not captured in well-defined

specifications [19]. Our implications and systems derived from them are therefore most applicable for supporting reflection-on-action. Such systems will likely differ from those used for managing design materials related to detailed design and implementation (e.g., these would facilitate reuse of source code, artifacts, or physical components from prior projects).

In this dissertation we concentrated on supporting reflection-on-action focusing on individual designers as opposed to reflection in an organizational setting. Our work is inspired by Schon's theory of reflective practice that suggested reflection to be a learning experience enabling critical thinking about one's own design. Research also considers reflection to be an enigmatic process. We believe that understanding and supporting reflective practice would require a narrowed lens and decided to focus on individual designers' reflective practice. Studying reflection in an organizational setting may offer new insight as designers in this setting have access to others artifacts and often encounter situations where it becomes essential to make sense and utilize artifacts created by others. How designers in such situations reflect could lead to new research directions.

In this dissertation we focused on artifacts that are either electronic (digital sketches, CAD models, Photoshop files, etc.) or have an electronic representation (scans of sketches, images of existing systems, etc.). During the early stages, designers create and utilize many physical artifacts, for example, doodle and notes on post-its, ideas written and posted on white-boards, physical prototypes, etc. While these physical artifacts are an important part of the early design process, many of these artifacts are only important for a certain period of time and are expected to serve their intended purpose and then discarded. Designers try to capture electronic representations of the physical artifacts that they consider valuable and believe would have value beyond their current usage. An exciting area of future research could be to understand designers' motivation and willingness to capture and utilize physical artifacts and understand what types of physical artifacts have value beyond current project, how to best represent these artifacts, and how they can be best utilized to support reflection.

Chapter 2

Related Work

Reflection is a key element of creative design that has been an important area of focus for design researchers for many years. In his theory of reflective practice, Donald Schön identified two types of reflection – reflection-in-action or in-the-moment reflection and reflection-on-action or post-reflection. Our work is inspired by Schön's conceptualization of *reflection-on-action*. In this dissertation, we focus on the design, development and evaluation of a system aimed to support activities associated with reflection-on-action. More precisely, our work investigates reflection practices, identifies challenges and needs surrounding reflection-on-action, and evaluates the efficacy of an interactive visualization system for supporting reflection-on-action.

In this chapter we discuss existing work in three key areas (reflection, research on creative design practice, and systems supporting reflection and creative design) that are most relevant to our work. First, we discuss theory of reflection and its influence on creative design. Second, we situate our work in context of other studies of design practice. We conclude with a discussion of systems supporting reflection and creative design. We also touch upon how and why existing tools have not enabled the benefits of reflection to be fully realized.

2.1 Reflection in Creative Design

Reflection is a central activity of creative design. It is often viewed as a cognitive process that allows a designer to develop new insight into her design, generate alternative solutions, and reframe the design problem [20]. Reflection is also considered to be a form of design knowledge gained through practical experience and influences assumptions, ways of working and decision-making [1], [2]. Researchers have long recognized the effectiveness of reflection as a learning tool [21], [1] suggesting that designers who adopt reflective practices can acquire better understanding of their design processes [1]. Design researchers also emphasized the importance of adopting reflective practices [13] and the positive impact it can have on design outcomes [22].

In his seminal work, Schön differentiates two types of reflection: reflection-*on*-action, which refers to post-event thinking (e.g., assessing lessons from prior projects), and reflection-*in*-

action, which refers to thinking while doing [23], [2]. Researchers have mainly focused on supporting reflection-in-action, resulting in tools that assist designers to act, think, and react to ongoing design activity (e.g. [24], [13], [11]). In contrast, there has been little research studying how designers engage in reflection-*on*-action such as identifying what questions are asked, how the questions are answered, what challenges are faced, or what tools might aid reflection-on-action. We believe being able to effectively learn from prior design experiences is equally important for improving design efficiency and outcomes. This dissertation contributes to identifying how the cognitive act of reflection translates into specific activities in practice and how systems can be developed to provide better support for engaging in reflective activities.

2.2 Studies of Creative Design Practice

There have been many studies of design practice. The areas that are most relevant to our work are studies of reflection, early design process, and knowledge reuse.

2.2.1 Studies of Reflection

Schön characterizes design activity as a "conversation with the materials" [23], associating the act of seeing with sense making, sudden discoveries, and learning from the present situation. These activities are collectively referred to as "reflection-in-action", which a designer consciously or subconsciously engages in [23]. Schön also defined the concept of reflection-on-action as post-design cognitive processes where prior design processes, decisions, and activities are re-visited [2]. This is useful, for example, to extract lessons and insights that can be applied to future design situations. Schön's influential work offers detailed observations of design activity related to reflection-in-action. However, this work offers fewer details about designers' practice of reflection-on-action, especially what questions of prior projects designers ask and what activities designers engage in during reflection-on-action. We extend Schön's work by eliciting the reflective questions designers ask and activities they perform in authentic design projects.

Embodied reflection is defined as an act or knowledge that arises through experience of the designer and is revealed in her actions [20]. This prior research focused on how tacit knowledge can lead the designer to unconsciously engage in reflection while working on a problem. Critical reflection is defined as a practice that brings unconscious aspects of experience

to conscious awareness, thereby making it available for conscious choice [25]. This thread of research views reflection as part of a designer's experience instead of a pure cognitive activity. The main focus is on the integration of reflective practices in the design process, allowing the designer to identify unconscious aspects of the design problem and rethink dominant design choices. Researchers also considered reflective practice as a life-long learning process enabled by self-analysis [26], [27].

Research has therefore emphasized the importance of adopting reflective practices and its impact on design outcomes; however, prior work lacks detail about specific acts associated with reflection-on-action. We contribute to this direction of research by studying explicit practices of reflection-on-action in design, identifying questions asked and activities performed.

2.2.2 Studies of Early Design Process

Research on the early phases of creative design has focused on different types of artifacts and how these artifacts (e.g., examples, sketches, and prototypes) impact the idea generation process [[28], [29]]. Bonnardel studied the influence of information availability on the idea generation process [30]. A separate thread of research centered on the creation and utilization of sketches and early prototypes to externalize early ideas [31]. Researchers also focused on facilitating ideation process by capturing the evolution history of an idea by recording progression of an artifact [32] and capturing the context of the ongoing design activity in a dedicated physical workspace [33]. Herring at el. studied how and why designers retrieve and use examples in context of a particular design project in the creative domains [28]. Researchers have also investigated the use of different representations of ideas during the Web design process [34] and the communicative roles of design artifacts [35].

Research on early stages of creative design thus focused on understanding in which ways different types of artifacts influence the idea generation process. We extend this direction of research by identifying types of artifacts utilized during reflective activities and providing details about designers' motivations for utilizing these artifacts and challenges faced during their endeavor.

2.2.3 Studies of Design Knowledge Reuse

Researchers have conducted several studies of knowledge reuse in the engineering design domains. For example, studies have probed the efficacy of case-based reasoning methods [36],

and component-based design [37], [17]. The impact of stored cases on decision making has been studied in software development, architecture, and manufacturing [38]. Researchers have also studied how storage and retrieval strategies affect reuse of engineering models (e.g. CAD models) [37], [17]. A common thread in many of these studies is the need for capturing discussions along with the reusable components. However, these studies have focused on late design or implementation phases when the requirements are better understood. It is therefore not clear how well the results from these studies translate into supporting reflective activities due to differences in the desired outcome (inspiration vs. specific solutions).

In contrast to these and similar studies, we have studied designers' practices of managing and utilizing artifacts across project boundaries to support reflection-on-action.

2.3 Systems Supporting Creative Design

The major threads of research related to our work are: systems supporting reflection, systems visualizing design artifacts and activity, and systems supporting design reuse.

2.3.1 Systems Supporting Reflection

From a systems perspective, prior work has primarily targeted reflection-*in*-action. For example, prior work shows how to capture the evolution of design artifacts [12], support analysis and refinement of design tasks [13], and enable parallel development of alternative solutions [11]. Another direction has been to increase the "talk-back" of design representations through interactive sketching [24], embedding software critics into the design environment [39], and spatial positioning of design alternatives [10], [13].

A separate thread of research enables designers to define relationship between materials (see Figure 2.1). For example, Freed enables designers to create visual-spatial views of their design artifacts and to define and explore relations between them [9]. The views can aid reflection, but the designer bears the cost of creating and revising them. This may be challenging for large projects and comparing views between projects may be difficult unless the designer is unusually disciplined at creating and applying a shared vocabulary and structure.

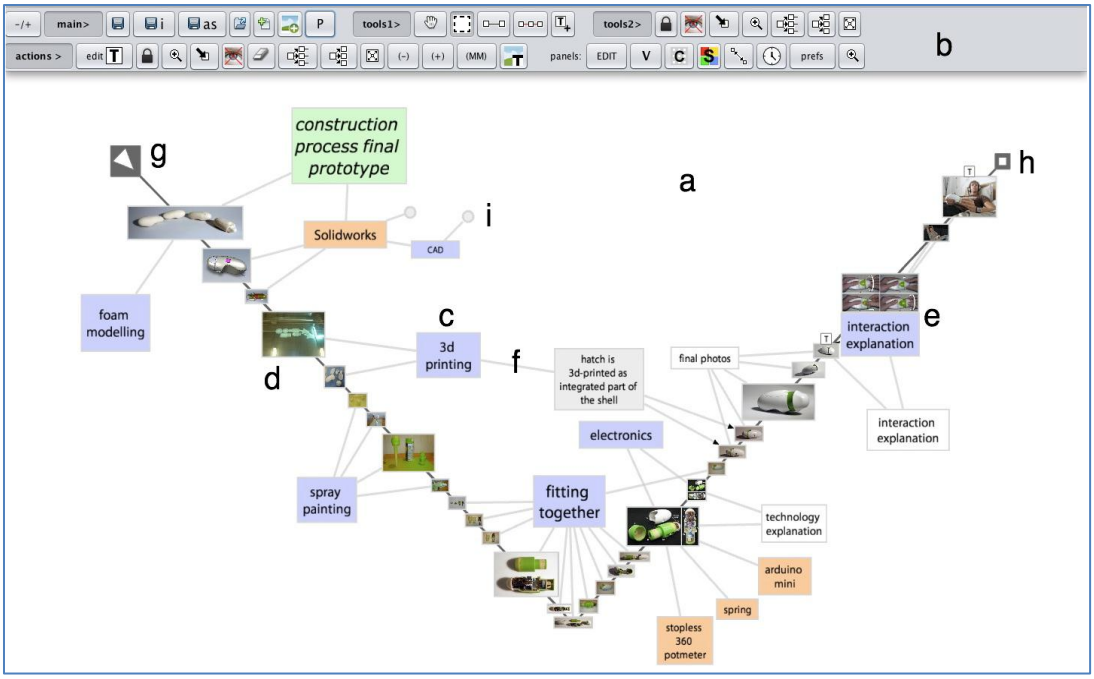
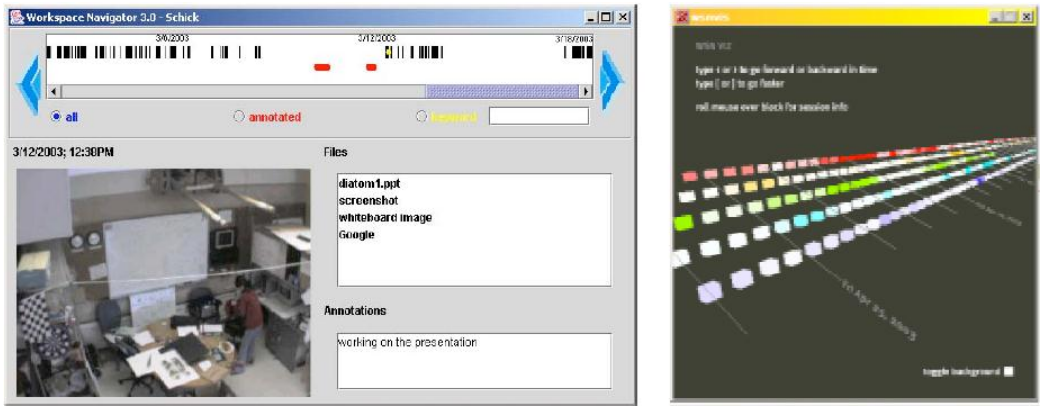


Figure 2.1: Different elements within Freed. a: canvas, b: main panel, c: text node, d: graphic node, e: combined text-graphic node, f: relation, g: start of a path, h: end of a path, i: minimized node. [9]

Relative to this thread of work, a major contribution of this dissertation is that we identified activities related to reflection-on-action and then contributed the design and implementation of a novel visualization tool that explicitly supports these activities. Our findings also provide guideline for designing better reflection support systems.

2.3.2 Systems Visualizing Design Activity

Research in the area of creative design has also shown benefits of visualizing artifacts and design activity. The WorkSpace Navigator (see Figure 2.2) provides a time-centric view of design activity that enables revisiting of prior situations [33]. The Designers' Outpost (see Figure 2.3) captures the edit history of an information architecture to allow revisiting and branching from prior states [32].



(a) (b)

Figure 2.2: WorkSpace Navigator (a) browser and (b) Visualization of design activity. [33]

These visualization tools aid in exploring prior states and design history but do not focus on supporting activities related to reflection-on-action (e.g. gaining an overall understanding of the entire project, comparing the process of multiple projects). We extend this thread of prior work by designing an interactive design process visualization tool specifically targeted to aid in answering questions related to reflective activities.

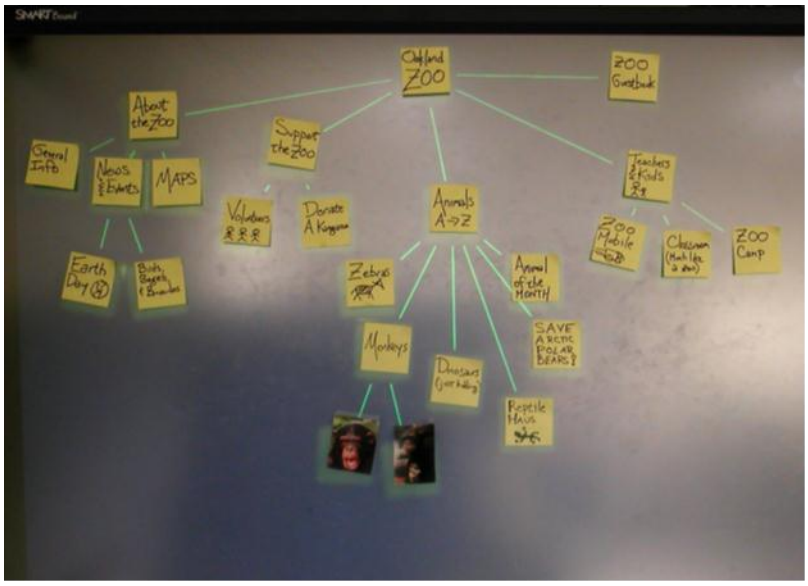


Figure 2.3: Designers' Outpost Interface. [32]

An emergent thread of research has focused on visualizing collections where the collections are created on the fly using tags as the grouping criteria [40] or can be created manually by the user to support specific information need [9]. Effective visualization for supporting reappropriation differs from keyword-based information visualization as the effectiveness for the former depends not only on providing context of the materials but also on facilitating the use of personal experience and interaction with the stored materials. Visualizing artifacts alone offers little value to the designers as they want to learn about the design process surrounding artifacts, recall the design decisions, and reminisce on their design process. User provided tags can facilitate effective categorization and management, but novel tagging mechanisms are warranted to make this approach a success. Our work extends this thread of research by incorporating activity context in representing artifacts – supporting designers' reflection needs.

2.3.3 Systems supporting design reuse

Existing design reuse systems fall into three broad categories: organizational memory systems, case-based design and rationale systems, and component repositories.

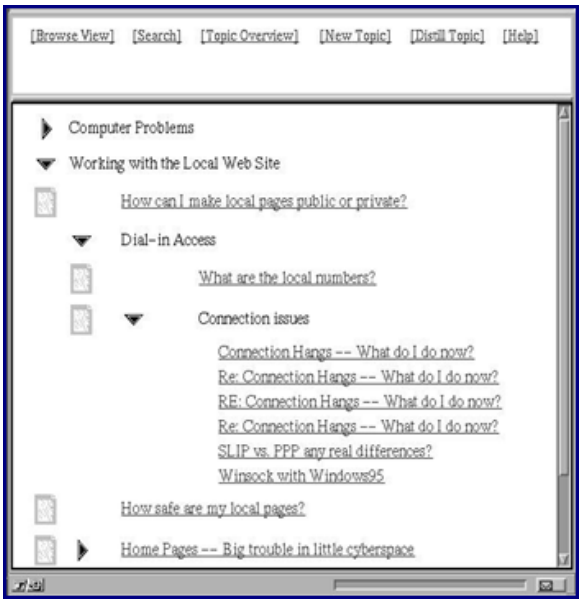


Figure 2.4: Organizational memory based system proposed by Ackerman. [41]

Organizational memory systems record solutions to well-defined and recurring problems and users can interactively navigate the repository to find needed information [41], [42]. However, these systems do not support storage, retrieval, or reuse of the myriad artifacts typical for creative design. Figure 2.4 highlights such an organizational memory-based system, which allows users to find answers for frequently asked questions but not design artifacts or design process.

Case-based systems bring computational processes to design repositories [43]. With effective representation and indexing, these systems aim to help designers find solutions from prior problems that may be useful in solving a relevant new problem [44]. Despite many technical advances, these systems have not been widely adopted by designers in the creative domains, especially during the early conceptual stages and for supporting reflective activities. We believe this indicates a lack of understanding of the work practices and needs of designers in these domains.

Design rationale systems (see Figure 2.5 for an example design rationale system) allow decisions reflected in design artifacts and related deliberations to be captured and traced [45]. This information can then be later accessed to support maintenance and re-design efforts. However, it is not clear how well this type of information would meet designers' needs surrounding reflection, when they are trying to recall the design process or seeking inspiration.

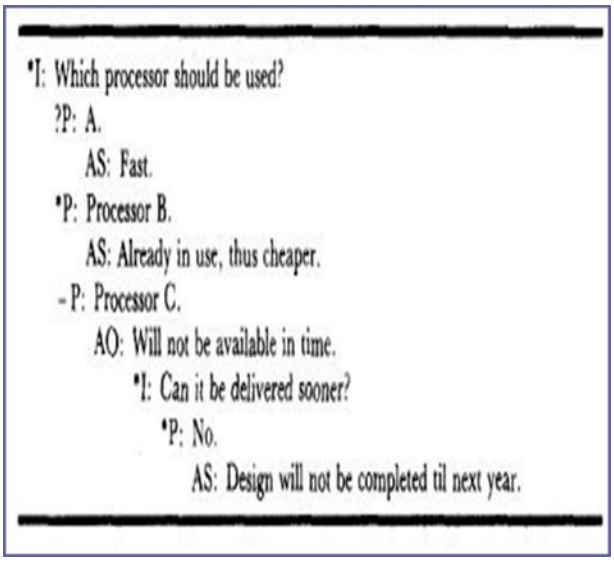


Figure 2.5: Design rationale system proposed by Conklin. [46]

Reuse of existing components and patterns is a common practice in many engineering design domains; especially to solve complex problems [42] and assist in decision making [18]. Research on reuse of existing knowledge has mainly focused on solving recurring problems where the solution (similar solution) has been utilized in similar situations before. These studies and resulting systems have focused on late design or implementation phases when the requirements are better understood and needed information can be searched using well-defined queries. In contrast, reflection in the creative design domains is often targeted for exploring materials that can provide inspiration, offer direction, and allow designers to make sense of the materials and the design process – leading to exploration of materials without any well-defined search criteria. Systems that focus only on indexing and management of materials based on keywords with no regard to the designers' experience or interaction with the stored materials are thus not very effective.

Many types of design reuse systems are available, but few, if any, have been widely adopted for creative design. We argue this is because such systems (case-based systems, rationale systems, etc.) do not adequately support designers' needs surrounding reflection, in part because such activities are not yet well understood. To help overcome this obstacle, this dissertation contributes understanding of designers' practices of reflection and offers guidelines for designing next generation reflection support tools.

In summary, our research contributes new understanding of designers' activities and needs associated with reflection and argues for better tools supporting reflective behavior. We also offer guidelines for supporting reflection-on-action and contribute the design of ReflectionSpace, a novel interactive tool for supporting reflection-on-action through a visualization of design process. Our design is motivated by designers' reflective practice, their needs surrounding reflection-on-action, and literature on design and creativity. Our work complements existing systems which are more focused on supporting late design phases, information organization, search, and management, and reflection-in-action.

Chapter 3

Understanding Reuse of Existing Information in Creative Design

Existing artifacts are an integral part of the process of reflection-on-action. The first step in designing reflection support tools is gaining a deep understanding of designers' current practice surrounding reuse of design artifacts –different types of activities related to reuse, artifact management and organizational strategies utilized, challenges faced, and unmet needs. The first phase of this dissertation thus focuses on understanding the details of reuse practices in the creative design domains, especially for the early design phases.

Prior knowledge is a designer's greatest resource [44]. For example, designers draw from their own and others' prior knowledge to formulate the design problem, generate ideas, and evaluate alternatives during the early design phases [5], [6]. By "prior knowledge," we are referring to the concepts, lessons, and representations captured in the myriad artifacts created or collected in the process of solving a particular design problem as well as in the designer's own memory.

Studies confirm that designers often access prior episodes (experiences) when challenged with new problems [7]. Due to the large volume and diversity of design knowledge produced even for a single project, designers must rely on external methods of storage and retrieval [36].This has spurred much research into systems that enable rapid access to and promote reuse of prior design knowledge; as such systems may improve design efficiency and outcomes [44].

For example, case-based repositories represent an important class of design knowledge management system [29].These systems allow prior cases (e.g. artifacts and descriptions) to be efficiently represented, indexed, and retrieved [43]. A second class of system allows the decisions and rationale relating to the construction of design artifacts to be captured [46]. The decisions can be traced to support redesign and maintenance efforts. Systems such as Wikis and blogs also show promise for managing design knowledge. However, despite many technical advances and availability of these systems, they have not been widely adopted for managing

design knowledge. A key reason, we believe, is that user's needs and practices for managing and reusing design knowledge have not yet been adequately understood.

In this chapter, we report results and share anecdotes from a contextual inquiry that investigated the practices of and attitudes towards managing and reusing existing design knowledge. The study consisted of semi-structured interviews with 14 professional designers and an online survey receiving 28 responses. Participants came from several creative design domains such as graphics, industrial, and interaction design.

One novel aspect of this phase of work is our focus on the creative design domains, where problems are often ill-defined and there is no one right solution [47]. We chose these domains because they are widely practiced, would benefit from improved knowledge management, and have been under-studied relative to the engineering domains for knowledge management and reuse. Another novel aspect is our focus on reuse in early design activity, which differs from prior works' focus on the late design and implementation phases.

Analysis of the interview and survey results yielded several important findings. For example, we found that (i) reuse of prior design knowledge is highly valued during early design activity, but seldom performed due to a mismatch between existing work practices and system assumptions; (ii) designers want to know about the 'stories' associated with design artifacts and be able to reflect on past processes; and (iv) search is necessary, but insufficient for retrieving prior design knowledge. These and other findings were distilled into actionable implications that can improve the design of knowledge management systems. Though not exhaustive, the implications provide a large and important step towards bringing the desired benefits of knowledge management into the early stages of creative design work.

3.1 Study of Knowledge Management and Reuse Practices in Early Design

The purpose of our user study was to develop deeper understanding of the practices of and attitudes towards managing and reusing knowledge during early design and to extract implications for designing support systems. Our study consisted of interviews with 14 professional designers and a Web survey which received 28 responses. Remuneration was $20 for an interview and a $10 gift card for a survey.

Of the 14 designers interviewed, 12 came from three large design firms with a long-standing reputation for innovation. The other two designers were highly competent freelancers.

The interview had 18 questions, probing designers' beliefs and strategies for creating, gathering, storing, and retrieving design artifacts. Interviews were semi-structured in that a script was used but tangents and anecdotes were especially welcome. Table 3.1 lists a sample of the questions asked.

Twelve of the 14 interviews were conducted in the designer's own workspace. This allowed them quick and easy access to physical and digital artifacts (sketches, notes, photos, etc.) and allowed us to observe their environment. One interview was conducted via phone and another via e-mail due to distance. Interviews lasted at most 90 minutes. At the onset of an interview, we asked a designer to briefly describe a recent or ongoing project, and to share artifacts and anecdotes from this project as much as possible to aid our conversation. For example, one designer was working passionately on a new drug delivery device, another was engaged in designing a new line of luxury watches, and a third was creating banking interfaces for a youth audience.

To gain further information after the interviews and collect additional stories of knowledge management and reuse, we created an online survey. The survey had 17 questions similar to those asked in the interviews. Twelve were multi-selection (i.e. more than one response could be selected). The listed responses were informed by the interview results, but participants could write in their own. Five questions were open-ended, e.g., describe your strategy for organizing design artifacts; describe a recent occurrence when design artifacts from past projects were reused, etc. A link to the survey was posted on newsgroups, forums, and listservs. Twenty-eight responses were received over two months.

Generation and Collection
How would you characterize a "design idea" as it relates to the conceptual stage of the design process?
What types of artifacts (e.g., sketches, photos, Web pages, etc.) are associated?
How many design ideas do you typically generate during the conceptual stage of the design process?
What types of artifacts do you collect to help with ideation and from what sources do you collect them?

Table 3.1: Questions asked during an interview.

How does generating multiple ideas benefit you?
What technologies (e.g. Google search, Flickr, etc.) do you use to help generate design ideas? Can you give examples? How effective are these techniques?
Storage and Organization
What strategies are used for storing ideas?
How important is it to maintain a record of your past ideas? Why?
For what purposes do you review design ideas generated from your own past projects?
How do you determine which ideas would be most useful to review?
How often and when do you review ideas from your own previous work?
Retrieval and Reuse
For what purposes do you review or reuse artifacts from your own or others' prior work? How often?
From where are the artifacts retrieved? How do you decide which artifacts to retrieve?
Where do you find these examples?
What techniques do you use to annotate design ideas to facilitate retrieval, if any?
What types of annotations do you use?
Experiences
What experiences do you have with technologies that assist in long term management of artifacts, if any?
From your perspective, what would be the benefits and obstacles for adopting and using such a system?

Table 3.1(continued): Questions asked during an interview. Similar questions were asked on the survey.

Interview and survey participants indicated their primary domain of expertise as: graphic design (17), industrial design (10), interaction design (5), mechanical design (3), product design (2), communication design (1), and other (4). This sample was highly experienced, with most having five or more years of professional experience. See Table 3.2.

Method	<5 yrs	5-9	10-14	15-20	> 20
Interview	4	5	4	-	1
Survey	5	7	10	3	3
Total	9	12	14	3	4

Table 3.2: Years of professional experience of the designers.

3.2 Study Results

We report results of our study structured according to the main steps of knowledge management in early design; idea generation, collection of artifacts, storage and organization, and retrieval. Though discussed separately, the steps often occur in parallel and their boundaries are not always clear, as design is complex and often ad-hoc. We discuss results by drawing collectively from the surveys and interviews.

3.2.1 Knowledge Generation

A core activity of the early design process is generating numerous design ideas [48]. Designers interviewed in our study reported that they typically generate a very large number of conceptual ideas for a given design problem, averaging about 50-100, but ranging anywhere from 2 to 2000. For example, one designer was developing a new forward-looking website for a large public university, and generated a minimum of 5 *"very different"* directions.

Consistent with the concept of divergent thinking [49], designers expressed that generating multiple ideas helps them understand the problem, prevents fixation, triggers new thought, and creates "a rich landscape of possibilities." Interestingly, most designers considered ideas relatively easy to come by, it was choosing the most promising ideas that required the most work and creative effort.

An idea was usually regarded as a 'new direction' relative to the existing ideas rather than incremental modifications. An idea was typically expressed via one or more sketches, storyboards, wire diagrams, physical mockups, or scribbled text phrases. These artifacts were used for exploring the design space, communicating ideas to users, clients, and team members,

and reflecting on the evolving idea space. Knowledge management tools that target early design must therefore support these types of informal representations of ideas rather than only polished 'cases' (cf. [18], [44]).

3.2.2 Foraging for Inspiration

Generating ideas typically requires substantial background research [50]. Designers stated that they spend many hours foraging for materials that inspire, support, or elaborate on new design ideas. For example, Figure 3.1 shows a sample of the materials collected by a designer for inspiration.

Figure 3.1: Inspirational artifacts collected from the Web.

This behavior reflects the perspective that creative insight comes from the prepared mind rather than 'aha' moments [50]. Designers struggled to express precisely what they were looking for, but they described wanting to be aware of current visual trends, product styles, and new technologies. This would help form new connections within the design problem and trigger new thought. Designers characterized this type of background work as necessary and important. Generating ideas in a vacuum was regarded as being too risky (e.g., there is a risk of unknowingly repeating existing designs or creating inferior designs due to lack of awareness of better solutions). The quantity of artifacts collected ranged from a few dozen to several hundred.

Indeed, better support for this type of example finding behavior offers a rich opportunity for future research [28].

Foraged materials came from three sources; the current project as it unfolded, myriad external information sources, and internal project repositories. As might be expected, project-specific artifacts included design briefs, user research profiles, competitive analysis reports, and client communications. External artifacts included physical products exhibiting a particular function, digital photos or videos of anything that caught a designer's eye (people, objects, or actions), visual templates, and color patterns and styles. These artifacts were collected from diverse sources such as the Web; online repositories such as Flickr, Google Image, and eBay; design forums and blogs; paper magazines; and shopping excursions to local stores. Finally, designers searched project-specific and external artifacts created or collected as part of previous projects. In two designers' words:

"I am always looking for designers that inspire me to see what they have done on the way for similar projects…so you hop in the website or something similar … and look at things that are parallel to things that you are working on at that time… that's always helpful I think, inspiring."

"I go back to my own [past projects]. I end up digging back through and even try to find connections. I don't do it enough, but when I do it, I find it very valuable just to go back and look through my notes from previous projects because so often there's some connection between just what I was thinking or some spark."

There was a strong and consistent belief that one of the best sources of inspiration was their own or colleagues' prior work. Reasons included that these artifacts were created or collected by people they know and trust and that they would likely be of high relevance, e.g., the artifacts were from a past project for a continuing client or from a similar project for a new client. It is difficult to separate past projects from external sources because artifacts stored with past projects may themselves have been collected from external sources.

Designers indicated that project-specific artifacts for the current design problem help them frame the initial problem space. But they use artifacts from past projects, coupled with their

own experience and intuition, for generating and evaluating solution possibilities. Unfortunately, despite the value that designers placed on these artifacts and their desire to forage through them, this was rarely done due to ineffective access, organization, and sharing capabilities.

3.2.3 Storing Almost Everything

Designers genuinely believed that storing design artifacts would yield future returns and, as a result, store almost all artifacts gathered or generated during early design activity. This is partly due to business reasons (e.g., to justify their bill to a client), but mostly because designers believed that these materials had immense intellectual value. Even if they were unsure as to when or why these artifacts might be later retrieved, they were simply too valuable to discard. For example, we observed entire bookcases (see Figure 3.2), filing cabinets, and shoeboxes filled with design artifacts from prior work. As one designer stated:

"I keep everything…my notes, my sketches, everything. A lot of times even old artworks that might have communicated well but not as well for a certain phase or a certain presentation, I will keep it because I know I will reference it back…there's something that didn't pass but might work well with this presentation or … be useful for certain things. So I never throw anything away."

Figure 3.2: Design artifacts stored from past projects.

Table 3.3 lists the common reasons cited in the interviews and the number of related responses from the survey for why designers store design artifacts. Aiding with future ideation, capturing the design process, and benefiting other designers were the main motivations. Design artifacts thus clearly serve purposes over time that move well beyond the reasons for which they were originally created or collected. For example, designers expressed that they would often review the collection of artifacts (not any one in particular) to gain a sense as to the overall process that was followed and use that process as a template for the current project.

Reason for Storing Artifacts	Responses
Aid idea generation	20
Capture the design process	21
Share with and help others	19
Facilitate story telling	14
Reinterpret design ideas	14
Reflect on design process	13
Other (e.g., ability to rework an idea)	7

Table 3.3: Reasons for storing design artifacts (max: 28).

An interesting outcome relates to what was not mentioned. Designers eschewed the reuse of solutions as-is from prior work as solutions for the current project. Reasons included the persistent need to present clients with truly fresh ideas, a designer's intrinsic desire to innovate, and that design problems in the creative domains represented by our study are ill-structured (i.e. no two problems are ever the same and there is always a better or different way). Systems that support reuse in these types of domains should therefore promote foraging behavior and reflection over solution finding, which contrasts with much prior work (cf. [51]).

We also asked designers what additional information or artifacts they want to store, but currently do not or cannot. Responses centered on wanting to store decisions, rationale, communications, and processes related to design artifacts as well as descriptions of how those artifacts were used or referenced in later projects. For example, one designer said he wanted to

have *"records of brainstorming sessions and communication history"* as a means for recalling decisions.

3.2.4 Strategies for Organization

We asked designers to explain their strategy for organizing design artifacts. The most common strategies spanned a mix of personal/shared and physical/electronic dimensions. Personal-physical strategies included the use of paper note-books in which designers sketch or write fleeting ideas and attach or glue supporting artifacts. It also included the use of personal shoeboxes and office cabinets to store artifacts (and notebooks once full). Shared-physical included the use of dedicated storage rooms and large cabinets accessible to all. Personal-electronic strategies included the use of folders on personal work machines, blogs, e-mail, and bookmarks. For example, electronic folders were typically organized using some combination of project title, date, and type of material (sketch, user profile, photo, etc.). Figure 3.3 shows how one designer uses a mail client for organizing design artifacts as this allows for people search.

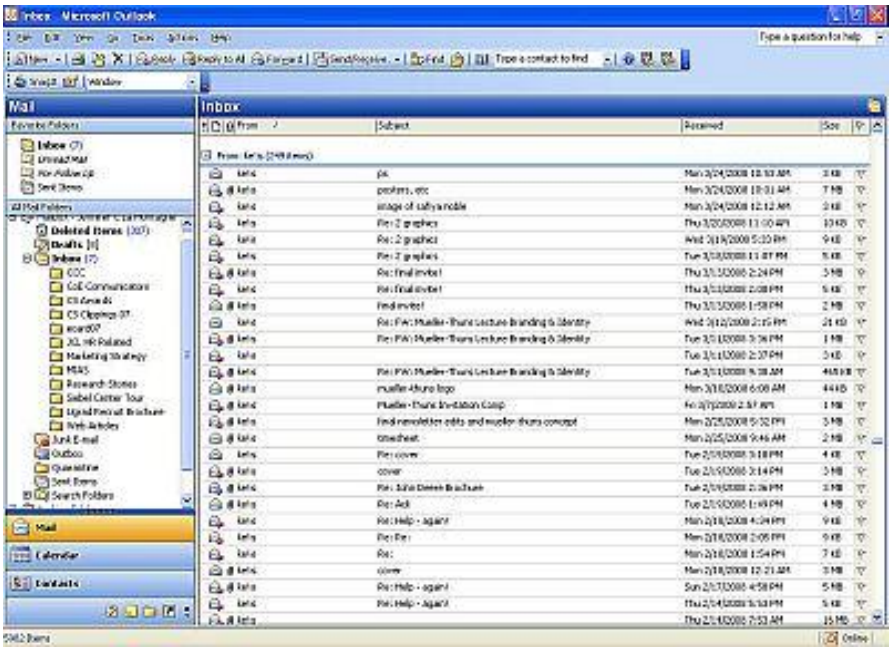


Figure 3.3: Project artifacts organized in an e-mail client, allowing the artifacts to be searched by person.

Shared-electronic included use of centralized file servers and enterprise Wikis. A designer typically employed a mix of strategies, varying by personal preference, project, and company. Table 3.4 summarizes the distribution of survey responses.

One important problem with existing organization strategies is that there is no consistent structure or naming scheme. Regardless of the strategy, designers universally called it *'messy.'* For example, this is how one designer described a typical folder:

"This is a mess. How many 'final' video, 'final' presentation, I don't know how many 'final' folders…it's so confusing."

Similarly, there was no consistent naming scheme for design artifacts and, even if there was a policy in place, it was rarely followed. This made locating others' files on a centralized server or Wiki nearly impossible:

"That's primarily what keeps me from going back. Everyone's project folder is organized in a very different way. Usually they are a mess. We don't have consistent file naming conventions. The closest we have is that the final folder will get highlighted or something. This folder was all over the place, it was a complete mess."

Organization Strategy	Responses
Electronic folders on personal machine	22
Electronic folders on central server	18
Physical folders and notebooks	17
Enterprise Wikis	8
Other websites	2
Blogs	1
Version control software	1

Table 3.4: Organization strategies used (max: 28).

Another problem relating to the use of centralized servers and Wikis is that designers were extremely apathetic about the prospect of having to upload all of their artifacts. It was just not exciting or enjoyable, causing a severe lack of motivation. Besides, clients compensated them for design and innovation, not for post project administration of files.

However, it was very intriguing that each firm represented in our sample was engaged in significant efforts to improve storage, organization, and reuse of design artifacts. These efforts involved adapting the use of enterprise-scale Wikis and formalizing naming conventions and link (folder) structures. This confirms that there is a need and desire in the design community to improve the practice of knowledge management, especially for supporting reuse of existing information. But it seems clear that such attempts will be largely unsuccessful without overcoming the contradictory work habits and motivational issues described here.

"We attempted hard to have a sort of internal database at [our company] of all our past projects, so in theory you can go and hunt down certain relevant projects. What we found is that it's very difficult to have that sort of management. It's a social problem because we've got quite a bit of flux and there's new people coming and going … It's a technical problem because information storage and retrieval is quite a huge task and there's quite a few projects happening at any one time so even finding those assets and getting people's behavior to adjust to the need to go through certain steps to document, it's not easy… when you're doing a project that doesn't feel like its immediately relevant because you can't easily anticipate the benefit that might come from you, personally documenting this for somebody else two years from now."

3.2.5 Retrieval and Search

Designers reported many reasons for retrieving artifacts from prior projects. Table 3.5 summarizes reasons given in the interviews and the related responses from the survey. Primary reasons included aiding the current process of idea generation, gaining inspiration for new ideas, comparing new to previous ideas, and proactively sharing information with colleagues. In the words of two designers:

"Early on in idea generation, I will retrieve artifacts to feed into the ideas being discussed and stimulate more ideas."

"A project was proposed recently which closely matched work that had been conducted five years earlier. The earlier project had not proceeded, but the ideas represented were as useful now as they were five years ago."

Reason for Retrieval	Responses
Aid idea generation	22
Gain inspiration	18
Share design information with others	16
Compare ideas	14
Reinterpret past design ideas	13
Reflect on design process	10
Search for expertise	7
Facilitate storytelling	7
Other (e.g., business development)	3

Table 3.5: Reasons for retrieving design artifacts (max: 28).

There were also several findings that were unexpected. First, Table 3.5 reveals that designers seldom retrieve prior artifacts for the purposes of storytelling (sharing lessons) and reflecting on the design process. Yet these were two of the main reasons that designers stated that they store artifacts in the first place (see Table 3.3). The discrepancy is likely because only the artifacts themselves are stored, without the associated stories or surrounding process. Though perhaps fresh in the mind of the designer at the time of storage, this knowledge dissipates over time [52].

Second, and perhaps as a consequence of the prior finding, we found that designers often review artifacts as a proxy for determining who to talk to about a particular design issue. For example, a designer may browse CAD files (and the creators, if available) to determine who has experience with designing a particular type of medical device. This was described as being more efficient and informative and less intrusive than broadcasting a company-wide request email.

For types of design artifacts, we found that project-specific documents, digital photos, sketches, Web pages, diagrams, and user profiles were retrieved most. But it is difficult to attach

a precise value to the retrieval of any particular material or retrieval instance. Value must be thought of from, and perhaps measured by, a more holistic perspective, e.g., gain in personal design skills, more satisfaction with the process, improved camaraderie among designers, etc. These types of measurements should be considered in future studies of design knowledge reuse in addition to the measures of process efficiency and solution quality.

Search was described as a necessary, but complex task for finding desired artifacts. For electronic stores of design artifacts, designers searched using the built-in capabilities of their tool or operating system. Searches were performed using known attributes of the desired item, the associated project, or people involved. Table 3.6 summarizes responses as to which attributes are used most often. Unfortunately, however, search was generally regarded as ineffective. One reason is because designers often store information on their local machine for convenience, making those artifacts inaccessible to colleagues. As one designer stated:

"I don't currently have a good way to search by designer. Also, design artifacts tend to get stored with their respective projects, not in a central design repository. Unfortunately, some projects have chosen different asset management systems, which makes cross project searching difficult."

Method	Responses
Project Name	23
Artifact Name	11
Approximate Date of Creation	15
Artifact Type	15
Location of the Artifact	15
Artifact Content	9
Designers Involved	9
Other (e.g., Client/project code)	3

Table 3.6: Attributes for searching past artifacts (max: 28).

This ineffectiveness often translated into the use of ad-hoc strategies. Here is what one designer reported doing:

"First I try to find the project or bucket folder I would save it in. [For example] if I'm looking for a skinning file I would go to the GUI design folder. If I can't find it that way, I search for it in spotlight. If it is a recent file and I know the application I made it in, then I'll open the application, go to open recent file, then when I find it I'll do save as and change how I saved it so I will be able to find it easier next time."

Personal information management systems such as [53] offer one approach, but do not address designers' need to share artifacts or capture the process and history. A second reason is that designers were often unsure as to exactly what they were looking for and therefore struggled to come up with appropriate search terms. A third reason is that available search tools are text-based, whereas most designers are visual thinkers. Visual search techniques such as CueFlik [54] would help, but techniques that would allow for visual foraging would seem most effective.

Despite being regarded as imperfect, search was still the dominant method used for accessing prior work. Most designers scoffed at the idea of having to navigate a mess of links and cryptic file names to locate items of interest from colleagues' (and even their own) past work, especially if they were unsure as to what they were looking for. This may explain why designers forage so heavily from the Web. Even if artifacts from past projects are more valued, the cost of access via the Web is disproportionately lower.

3.2.6 Social Aspects of Reuse

We found that design knowledge management and reuse is much more of a social process than we had anticipated, or that the research literature, especially on case-based design, has indicated. First, designers expressed wanting to browse other designer's prior work more than their own. This can be explained in part because a designer's work is already embedded in their own memory, experience, and intuition. Indeed, though it varied, many designers described looking back at their own work *"rarely"* and *"almost never."* However, designers described a genuine and professional interest in wanting to access, review, and learn from other designers' artifacts and processes, describing design as a continual process of learning and improvement. Also, we found that designers would be open to this type of sharing, assuming they could control

what was available and who could access it. Designers saw this as a form of reciprocity, e.g., to "*pay it forward - help others who have helped me.*"

Frequency	Responses
Every Day	10
Every Week	8
Every Month	4
Rarely (few times a year)	3
Never	1

Table 3.7: Frequency of sharing design artifacts (max: 28).

Second, designers reported that they often retrieved and shared design artifacts with colleagues that might benefit. For example, as shown in Table 3.7, 18 survey respondents stated they share their own design artifacts with colleagues (not on the same project) or other designers on a daily or weekly basis. This type of proactive sharing is initiated in response to knowledge requests broadcasted via email (e.g., "anyone know …"), reflections after group brainstorming, or meetings in which designers communicate progress and central obstacles for ongoing projects. The shared artifacts then prompt conversation and facilitate storytelling.

Finally, the few designers who made the effort to locate artifacts on a central repository or Wiki were unaware of whether others ever directly accessed or benefited from the artifacts. This could explain in part why other designers expressed lack of motivation for following their lead; they were unable to connect the effort of their contribution to the benefit that others received from it [55].

3.3 Key Findings and Their Implications

Here we discuss prominent findings of our study and, where appropriate, discuss their implications for building more effective systems for supporting reuse of existing design knowledge.

Reuse of prior knowledge is extremely valued in early design activity. Designers collect and evaluate many types of information from many sources in early design. Studying

relevant prior work and existing designs is often the first and most important step [50]. We found that designers value prior design knowledge for generating ideas, gaining inspiration, becoming aware of new trends, and reflecting on past processes. A critical point is that designers were not seeking specific solutions – they were seeking directions. The main implication is that designers genuinely value reuse, but better systems are needed to meet their needs.

Designers want to know about the 'stories' associated with artifacts. Storing artifacts alone does not capture the stories (e.g. the lessons, communications, and decisions) associated with them. Yet this is what designers were most interested in retrieving. We learned that designers would compensate by trying to seek the person(s) familiar with the artifacts so they could inquire about and learn the associated stories. One implication is that a reuse support system must provide a lightweight means for capturing stories with artifacts. The challenge is that this always requires some effort from users, effort they would usually prefer to direct elsewhere [56]. One possible solution would be to link communication applications such as e-mail and IM clients to the system (e.g., similar to [57]). This would allow designers to add lessons and stories with artifacts and reference these in the communication, which would be created and sent anyway. Archiving these communications would require minimal individual effort but will create a rich and evolving shared external memory.

Capture the process in which design artifacts were created. One valued reason for looking back at prior design artifacts was to gain a sense of the overall design process. For example, designers look back to reflect on their style of design or to use it as a template for an ongoing project. Storing artifacts alone fails to capture the design process.

Reuse support systems should provide a means for conveying the overall design process associated with the artifacts in a lightweight and informal manner. One possible approach for conveying the process would be through a structured visualization. Artifacts related to the same project phase (e.g. concept design, user research, example finding, etc.) could be spatially grouped or layered channels could be used to show when artifacts were added or modified for different phases of the process. Discussions surrounding artifacts could be captured through the use of tagging or lightweight commenting mechanisms.

Search is necessary, but insufficient for retrieving prior knowledge. When collecting relevant artifacts during early design, designers reported being uncertain as to what they were

looking for (e.g. looking for inspiration more than satisfying specific information needs). Search and rigid navigation will therefore not suffice; as also learned in [18].

To provide better support for reuse, in addition to search, one solution would be to employ the use of powerful information visualization and interaction techniques to support rapid visual foraging [58]. This would allow designers to explore the knowledge repository at their desired level of detail and reduce the burden of having to recall specific file names or locations. Visual information seeking [59] and exploratory browsing methods (e.g. berrypicking [60]) offer a useful starting point.

Sharing of design knowledge is common and not limited within the design team. Designers share design artifacts with colleagues in response to 'requests for help,' and other designers via design blogs and forums. Sharing is used to spark creativity, communicate ideas, and receive feedback. A few designers even felt obligated to share their artifacts as a means of repaying the broader design community.

One implication is that a reuse support system should allow designers to proactively flag artifacts for each other. For example, to respond to a knowledge request sent via email, a designer could flag relevant artifacts in the design repository, and a notification could be sent to the intended person. Systems would thus support not just retrieval, but a form of lightweight pushing.

Inconsistent organizational style impedes reuse. The use of messy and inconsistent organizational strategies severely hindered retrieval of prior design artifacts and discouraged reuse. For example, even when designers did upload their design artifacts to a shared repository, others were unable or unwilling to decipher the organizational or naming strategy used. This creates frustration and further impedes reuse. A reuse support system should not assume or impose the use of consistent naming schemes or folder hierarchies. As noted previously, one possible solution is to employ information visualization techniques that show pictorial representations of artifacts in different arrangements and/or with different levels of detail rather than only using folder hierarchies and file names.

In addition, relevant design knowledge is often too disconnected from the project at hand. Designers felt that prior projects were the most relevant sources of design knowledge, but reported relying on the Web and other sources (e.g., magazines) as these were immediately available. Several of the designers reported that their company had some form of a design

knowledge repository, but they had no idea where it was! This finding suggests a need for close integration of reuse support systems with commonly used tools for the particular design domain. For example, if a designer is creating a concept sketch with a design tool, other sketches from relevant or selected projects should be immediately accessible from the support system and alternatively, a support system should provide an application-specific overview of related artifacts when invoked from the tool.

3.4 Discussion

Design knowledge management is a very complex topic and studying it typically requires a narrowed lens. Our work is no exception. First, we studied a subset of design domains; including but not limited to graphics, Web, interaction, and industrial design. We chose these domains as they have been studied less in terms of knowledge management and reuse relative to the engineering design domains; but also produce large amounts of knowledge that must be managed. The domains studied are unique in the types of artifacts created (e.g., sketches rather than source code), but similar in that designers need to manage artifacts, processes, and decisions. Our findings and implications thus complement study results in other design domains, e.g., [17], [18].

Second, our research focused on early design activity, when designers are striving to generate novel design ideas. The type of knowledge created, collected, and applied at this stage is informal, ad-hoc, and rapidly changing rather than captured in well-defined specifications [19]. Our implications and systems derived from them are therefore most applicable for managing this type of early design knowledge. Such systems will likely differ from those used for managing knowledge related to detailed design and implementation (e.g., these would facilitate reuse of source code, artifacts, or physical components from prior projects). Further understanding is necessary to identify how such systems could be cross-referenced and integrated [18].

Third, we focused primarily on a particular form of design knowledge – ideas and representations expressed through all of the artifacts, examples, mockups, etc. created during early design. Though there was some intersection, our work did not explicitly investigate other forms of knowledge such as design rationale [46], [61] and communication [62]. Any design

knowledge management system must also reflect lessons from studies of these other forms of knowledge.

Fourth, effective design knowledge management systems can encourage reuse [37], [18], [7] but it is important to point out that the ultimate benefit must come from designers' willingness to contribute to and use such systems [55], [56]. For example, while almost all designers in our study expressed interest to review relevant prior designs during the conceptual stages, one designer considered this too constraining at this stage. Even if a reuse support system can greatly reduce the effort of finding relevant prior knowledge, it is the designer who is responsible for deciding how and when to use such systems in practice.

Finally, our methodology utilized contextual interviews and surveys because this was most appropriate for meeting our goal of understanding practices of and attitudes towards managing knowledge in early design. Other methods such as in-situ observation could be employed to complement our results by providing more quantitative insights, e.g., which specific artifacts are accessed and how often.

Results from this study informed us about the complexities associated with reappropriation in the creative design domains. We also learned that reappropriation needs would be best supported by creating effective representation of the existing artifacts. This motivated us to examine different types of tools, representations, and organizational strategies utilized by designers in practice. The next chapter reports the results of a study that digs deeper into effectiveness of different types of representations in supporting reappropriation.

CHAPTER 4

Designing to Support Reappropriation of Existing Knowledge in Design

Figure 4.1: Different types of artifacts displayed in a designers' workspace.

In the creative design domain, designers' reappropriation needs center on gaining an understanding of the design process, recalling design stories and rationale, and estimating effort. The study described in chapter 3 pointed out the significance of representing artifacts (i.e., concept, prototype, rationale, feedback, etc.) for supporting reappropriation. However, it also raised new questions about how to represent these artifacts. We observed designers showcasing their artifacts in their physical and digital workspaces trying to recall their process. Figure 4.1 presents the workspace of a product designer who displayed feedback on post-its, annotation on sketches, list of requirements, etc. hoping to recall her design process. While such physical spaces are common and may help to recall their process to some extent, they fail to answer many questions regarding context of design, effort invested, etc. Designers also work on many projects in parallel, making maintaining such workspaces difficult. In addition, for projects with many

artifacts this process of manually selecting and showcasing artifacts becomes extremely complex. In this chapter, we discuss the second phase of this dissertation, which focuses on understanding information management practices utilized by the designers to learn in detail about potential advantages and disadvantages of various representations. Based on our findings, we extract design goals for reappropriation support systems.

4.1 Methodology

We conducted an online survey followed by interview sessions with professional designers to learn about current information management strategies. We used the survey to learn about designers' existing practices and to recruit designers for the interview session. The survey link was posted in various online design sites, design blogs, and listservs. Thirty completed responses were collected in two months and six participants were invited to participate in the follow-up interview sessions. The participants came from different creative design domains (Graphic design, N = 12, Product Design, N = 7, Web design, N = 7, and others, N = 4). The participants work either in reputed design firms or are freelance designers. Participants professional experience range from 1 year 21 years, with average experience 6.9 years.

The survey had 10 questions centered on designers' existing practice – probing strategies and techniques utilized by the designers' for short and long term management and utilization of information. Responses from the survey shed light on different management strategies along with advantages and disadvantages associated with each strategy. The responses were also used to refine the design of early prototypes for aiding design information management. Six participants were invited to participate in the follow-up interview session (three graphic designers and three product designers, three working in firms and three freelancers). In these sessions participants were first asked to share information about their information management strategy, providing detail about the strategies utilized (both physical and electronic), and walk us through existing organizational strategies that they currently use. In the second phase of the session, participants were provided with different prototypes and asked to comment on the potential advantage and disadvantage of the proposed prototypes. They were encouraged to discuss features that they consider important for supporting their reappropriation needs and are missing from the current prototypes. The prototypes were refined after each interview session

and are designed to realize our lessons from study 1 (described in chapter 3) and the feedback received from the interview sessions.

Three of these six interview sessions were conducted face-to-face in a research lab and the remaining three were conducted over Internet using Skype video chat due to the physical location of the participants. Each of these sessions was audio and video recorded and photos and screen captures of participants' information management system were collected. A set of questionnaire designed using participants survey response was used to guide the conversation, but tangents were especially welcome. Each of the interview session lasted around 120 minutes and designers received $30 for participation.

4.2 Findings

4.2.1 Design Information Management Strategies

Most design information management strategy combines the utilization of physical and digital tools. Sketchbooks and notebooks are used by almost all designers as a medium for generating and storing early ideas. Sketchbooks are often the first place where designers jot down their ideas and draw early sketches. They also use their sketchbooks for writing quick notes on discussions and feedback received from the clients. When the ideas get more refined (termed as 'concept'), designers switch to electronic methods for creation and storage. While sketchbooks are still preferred for capturing fleeting initial ideas quickly, electronic mediums are preferred for long term management of concepts. We also observed designers scanning sketch books and physical meeting minutes and taking photos of early physical models to store these along with other electronic artifacts for the project.

Designers almost always keep their artifacts. A vast majority of the designers associated them as "packrats" and mentioned keeping everything they generated without any specific reason in mind. Further discussion, however, disclosed that most of the designers look back at their artifacts for a variety of reasons and subconsciously try to manage these for future retrieval. The following quotes exemplify this tendency of designers:

"I tend to be a natural packrat, so cataloging is a core part of my personality. I still have the vast majority of everything I have ever created (thousands of sketches, notebooks, photos,

videos, etc.) or at least some representation of the project (images of a product for instance).” - P6, Expert, Working in an Organization

“I have a scratchpad project where all of the mockups and snippets of ideas are permanently stashed. I revisit them every now and again for inspiration.” – P11, Expert, Working in an Organization

“I have a specific way I approach organizing my files -- I usually always start out with a "mood board" or "research" folder if the project involves new conceptual direction. I gather images in those folders that relate to the topic at hand. When it comes to actually executing my concepts, I create my file (indesign, illustrator, their corresponding links, etc.) and do "rounds" of iterations. After each exploration is presented to the client/an audience and I am given critical feedback on it, I create a new "round" folder and copy the files/ideas from the previous round into it, and edit it down. By the last round, I usually have honed in on the exact design direction everybody is most happy with. If I am ever asked "well, what about that one design you showed earlier, why didn't we choose it?" I can go back in my rounds, and figure out where that idea/design fell out in the running.” – P1, Expert, Working in an Organization

While designers capture early ideas on notebooks, sketchbooks, post-it notes, and pieces of paper, eventually the ideas (concepts) that get discussed and picked up for further consideration get transferred in a stable medium (physical sketchbooks, electronic sketches, scanned images, etc.). One designer mentioned *“transferring in electronic medium as a way of filtering and selecting the good concepts.”*

4.2.2 Representing Artifacts

Supporting alternate views of the stored artifacts is essential for supporting different design activity. While a standard file-centric view may help designers find artifacts quickly (assuming the designer is aware of what file is s/he looking for), a visual overview of artifacts will assist looking up for specific types of artifacts quickly. The major management strategies currently utilized by the designers are discussed below -

4.2.2.1 Directory-based Representation

Every designer uses directory-based folder structure for capturing and managing their artifacts. While this model offers familiarity - designers struggle to create appropriate categorization for organizing different types of artifacts, subsequently making it difficult to retrieve needed artifacts. Figure 4.2 sheds light on the struggle that designers face with managing their artifacts using this directory-based structure. In this project space of a web designer, project names start with numbers which indicate project-priority. "x" in front of project name indicates the project is mostly done, and highlighting indicates need for revisit. Each project folder contains sub-folders and each sub-folder contains artifacts belonging to that particular design iteration. This designer also tried to capture her design process by creating different folders with specific names, such as round 1 contains all the concepts generated in the first iteration of the project.

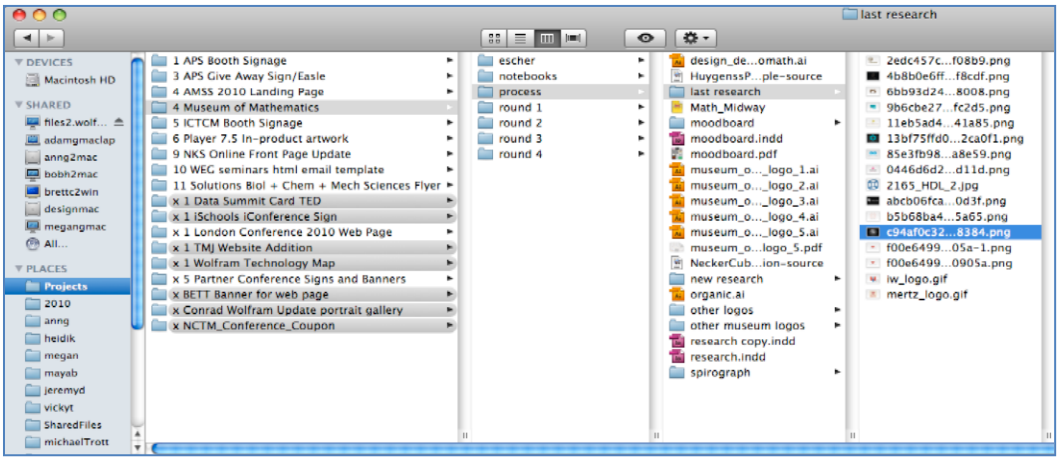


Figure 4.2: Design Space of a web designer - such spaces are typical for individual designers and design organizations for managing artifacts.

The directory-based structure is also unsupportive for capturing the progression of the design process. Designers often use naming strategies along with a number of sub-folders to overcome the limitations that a directory-based management style supports. Designers who originally create the folders and name these often forget the reason behind choosing the specific name. We observed designers who abandoned the use of "descriptive naming" as they mentioned that it was hard to come up with good descriptive names and even if they did come up with one, after a while they will forget what it was. The complexity of this management strategy

overwhelms the designer who created it, let alone other designers who may try to revisit artifacts generated by this designer. This directory-based structure fails to encourage reappropriation in organizations where each designer uses their own management strategy, making it almost impossible for others to decipher and find needed artifacts [63].

4.2.2.2 Activity-based Representation

Another information management strategy centers on utilizing task-status of design activity. Three out of six designer participating in the study mentioned utilizing their desktop to track ongoing design projects and ongoing tasks within the projects. Figure 4.3 represents the desktop of a industrial designer who regularly updated her desktop by placing ongoing project folders at top-left corner of the desktop and files that she was actively working on directly across the folder.

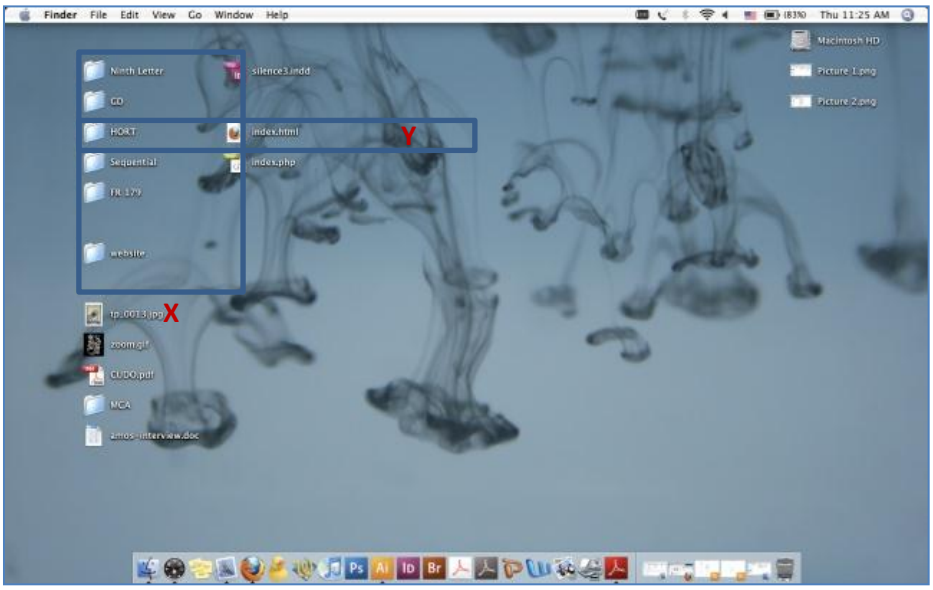


Figure 4.3 (a): Activity-based management of artifacts. Desktop-based management. Active projects are placed in top-left corner (X) with active files under those projects placed right (Y).

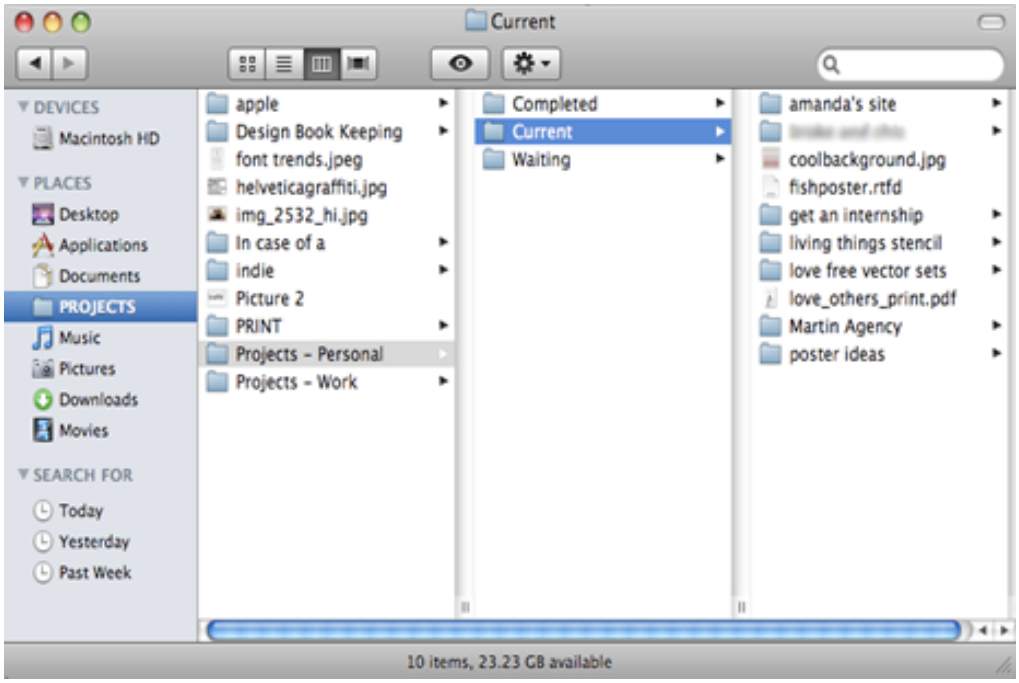


Figure 4.3(b): Activity-based management of artifacts. Status-based management. Folders are named to reflect different task status.

Upon finishing working on a file (and project), she removed it from the desktop and placed it in the design materials folder. This type of representation (4.3(a)) allows quick access to needed artifacts and acts as a reminder of unfinished and required task. However, this strategy acts as short term reminders of what to work on, forcing designers to use other strategies to support organization of their overall artifacts.

Some designers also mentioned using descriptive folder names to indicate the status of the project and the artifacts to differentiate between artifacts utilized for the different phases of the design process. For example, figure 4.3(b) shows a graphic designer's artifacts with folders named completed, current, and waiting. Each of these folders was used to represent the current state of the project. For example, the "current" folder contained projects that the designer was actively working on while the "waiting" folder contained projects that were sent to the client and waiting to receive clients' feedback. However, the designer mentioned difficulty categorizing projects in these three categorizes as some projects had sub-goals and continued for a long time; sporadically requiring artifacts generated from other projects or earlier phases. These project folders also contained artifacts that were originally generated for other projects, creating multiple

copies of the same file and storing these in multiple folders with different status and forcing the designers to remember which copy she used for a project and the reason behind it. The designers also had to manually move artifacts from one folder to the other depending on the current status of the project and its artifacts.

4.3 Categorization of Artifacts

Designers expressed a need for flexible categorization of different types of artifacts. As accessing artifacts is the only method available to a designer for revisiting a project, it is essential to allow designers to categorize artifacts quickly and easily. The only categorization strategy available currently is creating folders for different types of artifacts or for different phases of the design process. Frustrated by the lack of flexible categorization strategy, designers try to use tags, folders, and descriptive naming, but abandoned these as they become complicated, time consuming, and less effective with growing number of projects and artifacts. For example, one designer mentioned using tags as a way for categorizing her concepts, but felt challenged to come up with tags that would assist revisit. All her scanned concepts got tagged as scans, offering little insight about the scanned artifacts themselves. Another designer mentioned trying to use color-coding to differentiate different types of artifacts, but this strategy also failed as the same artifact can become part of multiple design phases or serve differently for different stages of design. Another designer tried to use color-coding to categorize artifacts depending on their status (see Figure 4.4), however this strategy lost effectiveness with increasing number of projects. Effective categorization is vitally important for retrieval of needed artifacts. However, every designer experienced difficulty in categorizing needed artifacts that would allow easy retrieval, forcing them to use ad-hoc strategies to find needed artifacts.

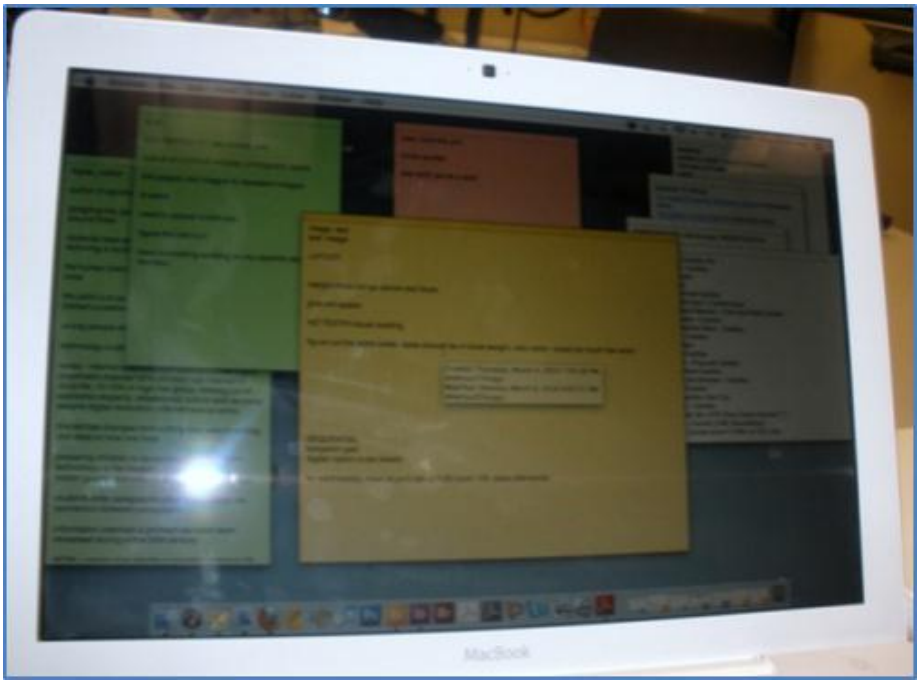


Figure 4.4: Color-coded feedback and design notes on a designers' desktop. Color is used to indicate project category. Gray-notes indicate personal projects, while yellow notes indicate group projects.

4.4 Relationship between Different Artifacts

An artifact can be a sketch, a note containing minutes from a client meeting, an e-mail containing comments and feedback, rationale for selecting a direction or electronic prototypes. One artifact can be related to different types of artifacts such as sketches, examples that inspire the sketch (e.g., navigation bar in an existing website when designing a new website), feedback from clients and other designers about the sketch, refinement from earlier concepts that result in the final concept, etc. While physical sketchbooks allow some flexibility for capturing components such as scribbled notes, sketches, and post-it-notes in one space, this is limiting due to the limitation in types of materials that can be connected. On the other hand, electronic design spaces lose association between these different artifacts as each artifact is stored as a separate file and currently there is no support for specifying association between these files easily. Figure 4.5 represents a variety of artifacts which one designer utilized to represent her concept for a project.

This figure doesn't contain the electronic artifacts that she used in addition to these physical artifacts. This figure also exemplifies the close association between different types of artifacts. While some of the design components are valuable only for a specific period and don't require capture, designers often expressed interest in capturing many artifacts related to the concepts and attributed high value in revisiting these artifacts at later points in time.

Figure 4.5: Relationship between different types of artifacts. All these artifacts represent the relationship of communication outcomes, sketches, feedback, color-coded notes, and final design for one idea which loses its meaning when stored in a directory-based structure as separate files.

4.5 Design Goals

The goals for designing an effective design management system emerged from the implications generated based on the findings from the studies described in chapter 3 and from our ongoing discussion with the professional designers about their information management practices during the design sessions. We identified the following goals that are critical for supporting reappropriation in the creative design domains, details are provide below.

- Providing awareness of existing artifacts by novel visualization irrespective of the organization structure used
- Making the artifacts and the surrounding design process visible
- Supporting reflection on design
- Exploring artifacts based on association
- Providing better access to the artifacts to improve searching
- Providing access to intangible elements of design
- Connecting narratives with associated artifacts

G1: Providing awareness of existing artifacts by novel visualization irrespective of the organization structure used

One of the main reasons that hinder reappropriation is a lack of awareness of needed artifacts resulting from the inconsistent and often cluttered organization structure used for managing them. The file-centric approach used for organizing artifacts often fails to provide awareness of the artifacts' existence [64], [65], hindering reappropriation. Additionally, in the early design stages, designers are often unsure about what exactly they are looking for and filenames are insufficient to provide better idea about an artifact. An effective support tool should provide a visual overview of the entire landscape of artifacts - allowing designers to make sense of them. Allowing designers to browse through the artifacts in different levels of detail provides better support for finding artifacts of interest than using keyword-based search in a folder hierarchy [66], [67], [60].

G2: Making the artifacts and the surrounding design process visible to provide better context

Representing the design process surrounding artifacts is tremendously beneficial. Designers want to see the artifacts in relation to the other artifacts utilized for that project. They want to know when in the design process the artifact was created, what other artifacts were created or utilized at that time, how much time were spent on that design phase, the rationales driving the design, etc. [63]. A reappropriation support system should make the design process surrounding artifacts visible to allow designers to explore the artifact in context with other

artifacts utilized in the process. It should allow designers to recall the decisions made and to convey their design choices to others.

G3: Exploring concepts based on association

One of the main limitations of existing file centric approach is a lack of support for exploring associations between different artifacts. In creative design, artifacts can be associated by different relationships, for example, all artifacts generated for conveying a particular idea are associated by the common theme, a sketch can be associated with the example images that inspired the sketch, variations of a concept used for conveying the same idea are associated as part of the same idea, etc. A designer can also associate artifacts based on their aesthetics, materiality, functionality, or any reason that makes sense to her. An effective reappropriation support system should allow designers to define and explore artifacts using these associations. It will allow designers to make better sense of the existing artifacts and help recalling the context of design - which are more natural than remembering exact filenames.

G4: Supporting reflection on design

Reflection is an integral part of a designers' work practice [2], allowing designers to make better sense of their design, learn from past experiences, and utilize these lessons for self-improvement. Existing file-centric systems allow storing artifacts in folder(s) which designers can name and organize. However, with elapsing time designers experience difficulty in remembering why they have created a certain folder/file or collected some artifacts or why they made a design decision or how did a concept evolve with time. Even when all the artifacts are stored electronically inside a project folder, it is impossible to reflect on the design process by looking at the long list of filenames under a folder(s) [63]. A reappropriation support system should offer better representation of the design activities – making cues of prior interaction visible and showing the artifacts utilized and time spent on the different phases, annotations and notes highlighting design choices made and feedback utilized for refining the concepts, associations between different artifacts, progression of the design, etc. Using a time-based visualization showing the progression of the design activity would provide better support for reflection on the design process, for example, instances such as creation of sketches after generating prototypes may allow recalling the decision to explore a new design direction not considered before and attached notes may allow recalling the reasons behind these design

choices - which is extremely difficult if not impossible to understand by looking into a folder full of different types of files.

G5: Providing better access to artifacts to improve searching

Though not effective, search is still the dominant method used for finding needed artifacts. Designers work with many types of artifacts, each of which serve different purpose in the design process. Designers want to access and utilize these varying artifacts differently at different times. For example, prototypes generated for one project can serve as example for a new project. However, lack of flexible access method forces designers to either store an artifact in a single space (inside a project folder) or create multiple instances of the same artifact and store it in multiple places to allow retrievability. Both these methods fail to utilize past access and interaction history, which is an important context information often utilized by users when searching for an information [53], [68]. A reappropriation support system should allow designers to access artifacts using a combination of searching and browsing along with association information integrated with an artifact. Providing an expandable vocabulary of association to allow designers to define association among artifacts would offer better accessibility.

G6: Providing access to intangible elements of design

Design is a complex process and making intangible elements of design (e.g., time spent on a project or on a particular design phase, number of access to projects and artifacts, stories and anecdotes regarding artifacts, design phase where an artifact was created, etc.) visible could encourage reappropriation. Designers often use artifacts as a proxy to reflect on the design process [63] and designers value these information associated with an artifact. For example, a designer may want to know how many times and when an artifact has been accessed, why did a project took longer than usual?, how many artifacts were generated for a project or projects typically for a specific client?. A reappropriation support system should make these invisible elements of design visible to provide important information about the designers' work process. Visibility of such information can provide important cues about past successes and failures and allow the designer to reflect on her own design activity.

G7: Connecting narratives with associated artifacts

Communication about artifacts plays an important role in the creative design process. Different types of communication influence the design process differently. For example, discussion surrounding existing artifacts promotes design thinking [69], feedback received on

early ideas allows designers to refine those ideas and develop alternatives [6], and communication with clients regarding sketches and early prototypes help to contextualize the design process [30] and convey design decisions [70]. Communication surrounding artifacts allows the designer to better understand the design process and thus encourages reappropriation. While design rationale systems allow designers to capture rationale, the high effort required for uncertain future benefits make designers unwilling to utilize these systems [63], [71]. While designers may be unwilling to spend a lot of time for creating a record of all communications associated with a project, they may be more willing to record narratives in a lightweight manner and attach those with related artifacts. A reappropriation support system should allow designers to integrate and examine not only rationale but also any communication outcomes that designers consider important with the associated artifacts with low cost.

Chapter 5

Understanding Reflection Practices in Creative Design

Our study of designers' reappropriation behavior offered insight about specific activities that need to be supported to facilitate reappropriation needs. In chapter 4 we discussed design goals for different types of systems (e.g., idea management system, search and retrieval system, etc.) that can be designed to facilitate reappropriation needs. Of the activities that motivate reappropriation, *reflection* emerged as one of the key activities that designers consider imperative for design success. This motivated us to focus on supporting reflection.

Reflection is a central activity of creative design. It is often viewed as a cognitive process that allows a designer to develop new insight into her design, generate alternative solutions, and reframe the problem [20]. Reflection is also considered to be a form of design knowledge gained through practical experience and influences assumptions, ways of working and decision-making [1], [2]. Researchers have long recognized the effectiveness of reflection as a learning tool [21], [1], suggesting that designers who adopt reflective practices can acquire better understanding of their design processes [1]. Design research also emphasizes the importance of adopting reflective practices [13] and the positive impact it can have on design outcomes [22].

In his seminal work, Schön identified two types of reflection: reflection-on-action, which refers to post-event thinking (e.g., assessing lessons from prior projects), and reflection-in-action, which refers to thinking while doing [2], [23]. Most researchers have focused on supporting reflection-in-action, resulting in tools that assist designers to act, think, and react to ongoing design activity (e.g. [24], [13], [11]). In contrast, there has been little research studying how designers engage in reflection-on-action such as understanding what types of questions are asked, how the questions are answered, what challenges are faced, or what types of tools might aid reflection-on-action. We believe being able to effectively attend to prior design experiences is equally important for improving quality of design.

Our work is inspired by Schön's conceptualization of reflection-on-action, but aims to identify how the cognitive act of reflection translates into specific design activities in practice. To achieve this goal, we conducted twelve in-situ discussion sessions with professional designers to learn about their goal, strategies, and techniques for engaging in reflection-on-action. We found that designers want to think holistically about prior design processes, estimate effort invested at different design phases, extract design "stories," compare projects in terms of the processes utilized, revisit "successes" and "failures" and assess progression in the current design project. Most designers mentioned engaging in reflection-on-action frequently and the ineffectiveness of using traditional file management tools for exploring and examining design materials during these activities. The key contributions of this phase of work is identification of activities associated with reflection in design practice, strategies for performing these activities, and challenges faced when performing the activities.

5.1 Understanding Reflection-on-Action

We conducted 12 interview sessions with professional designers (average experience was 6.9 years) from graphic design (N=6), product design (N=4), and architectural design (N=2) to learn about their reflection practices. Participants were recruited by posting an invitation in local design distribution lists and using a snowball sampling technique. Participants were remunerated $30.

In these sessions, participants were first asked to share information about a recent project where they consciously engaged in reflective activities and to show us physical and electronic traces of these reflective activities where possible. This helped to ground the discussion about the various strategies they had utilized for engaging in reflection. Participants were then encouraged to discuss their overall experience surrounding reflective activities and how that influenced their design outcomes. We requested our participants to enumerate specific questions they ask during reflective activities and encouraged them to show us artifacts used in this process. We utilized a questionnaire to guide our discussion, but welcomed tangents. See Table 5.1 for a list of questions asked during the sessions.

Each session lasted two hours, was audio recorded, and later transcribed and analyzed using a grounded theory method [4]. We collected all electronic artifacts from one project from each designer a priori. We also collected images of the physical artifacts and captured screen

shots of the electronic tools and techniques detailing strategies utilized by our participants. We followed up via e-mails for collecting additional materials that might clarify their reflective practices.

Reflective Practice
What does reflection mean to you?
Why do you engage in reflection?
How often do you engage in reflection?
What types of design activity typically involve reflection? (Problem formulation, Goal analysis, concept generation, concept refinement, solution evaluation, other?)
Tools and Techniques
What type of structure or representation do you utilize to support your reflective practice?
What tools do you leverage for engaging in reflection?
What challenges do you face when trying to engage in or during reflection?
Reflective Activities
What type of design materials do you typically utilize during reflection, if any? What are you trying to achieve?
What questions do you ask yourself during these reflective sessions?
How do you reflect on ongoing and past projects? What are you trying to achieve?
How do you capture/translate the lessons from reflection in your design? What challenges do you face when trying to do so?

Table 5.1: Questions asked during the discussion session.

5.2 Study Results

5.2.1 Motivation for Reflection

Recalling, Constructing and Communicating design stories: Participants reported the need for constructing "stories" about the process utilized, rationale for choosing a particular direction, and project milestones in terms of ideas selected, prototypes created and refined. For example, to convey her design process to the client, participant P6 reported creating a presentation containing design requirements, selected research and inspirational materials, a few

early sketches, three mid-level concepts, and the final design. This presentation acted as her "story" - enabling her to "show her process." In this dissertation, we define "design story" as a description about the design process or artifacts. Stories include various aspects of the design process and the artifacts, often elaborating the choices that designers make and capture the context in which the design concepts evolved during design lifecycle. Designers want to recall and communicate such *stories* about their design. Storing artifacts alone does not capture the stories (e.g. the lessons, communications, and decisions). All of our participants emphasized the importance of story construction for communicating their design and expressed a need for tool support for constructing stories.

Analyzing design process utilized: Designers want to analyze and compare different projects in terms of the process followed and to gauge their progression as a designer and examine changes in design process and style. For example, after completing a design project, participant P1 reported revisiting client communications to examine the project goals and final outcome. We observed designers retaining electronic communication materials and also creating electronic copies of their physical communications to help revisiting the process utilized.

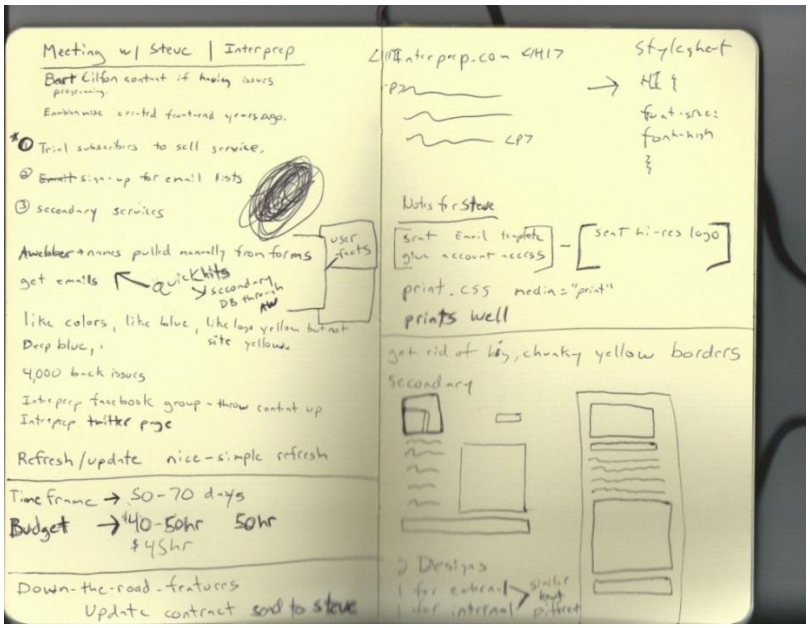


Figure 5.1: Minutes from a client meeting highlighting design requirements. This page was scanned and stored with other electronic materials for this project.

During design session P1 explained his motivation for capturing and preserving these records:

"You reflect on your past design so that you can have that informed decision, definitely reflecting on what has occurred and use it always to improve your design. It's a learning experience, what have worked and what haven't, and you also go back and think about (the problem)." – P1

Understanding context of design: Designers reported asking themselves, '*what was I thinking at that time*' and explore materials to understand what inspired, motivated, or led to a specific design activity. This process of exploration continues until the designer finds enough materials that offer '*sufficient context*' or abandons it after several unsuccessful tries.

Estimating effort invested: Designers revisit past projects to get a sense of time spent and effort invested before starting a similar new project. They also want to gauge their productivity by analyzing how much time they have spent approximately on the different design phases. While design involves cognitive activities that don't have external representation, the participants considered the time spent on collecting, creating, and refining materials as a good approximation of their invested effort.

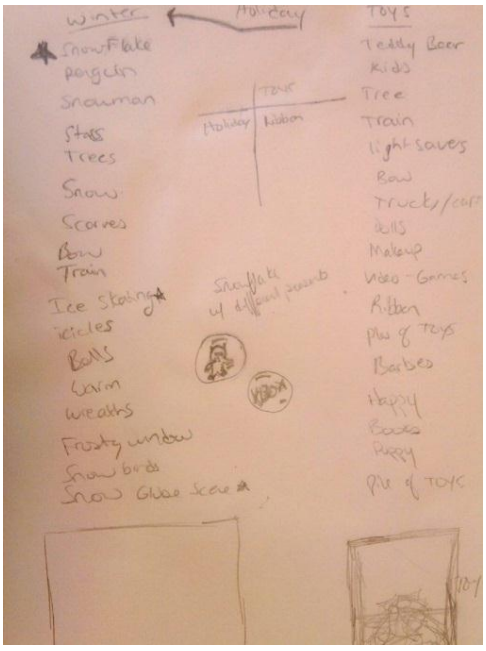


Figure 5.2: Annotation with special markers to indicate preferred idea.

Exploring preferred materials: Designers explore favorite/successful materials to gain inspiration, to train their eyes and mind, and to achieve a creative state of mind. Indicating preference by adding special markers such as *"stars"* was common for physical artifacts (see Figure 5.2). For the electronic materials, accessing "preferred materials" involves searching and browsing several project folders using file names, locations, file types, or any other information the designer can recall. A few designers (3 out of 12) also mentioned creating separate folders for storing these *"preferred materials."*

Reliving design moments: Designers revisit past projects to relive specific design moments often to *"feel good"* and to get a glimpse of past design activities and process.

5.2.2 Process of Engaging in Reflective Activities

Depending on the motivation for engaging in reflection, designers adopt different strategies for exploring stored materials. When trying to get an idea about the process utilized in a past project, designers explore, analyze, and compare materials from current and past projects. For example, to design the navigation style of an e-commerce web site, participant P3 mentioned exploring materials from an e-commerce site that he designed in the past. These past projects and materials often act as references for the ongoing or future project.

Design involves many activities that do not have any external representation such as exploring materials on design blogs or browsing design magazines to know "what's in and what's out". Even activities that have external representations in terms of electronic files or scans of sketches, designers struggle to assess their effort invested for these activities. Most of our study participants, especially freelance designers, mentioned struggling to convey to their clients how much time and effort they have spent on these activities and on each of the design phases or for the project overall. Designers themselves also want to know approximately how much time would be necessary for completing a similar future project. For estimating effort invested designers currently examine all materials created for a project, often starting with specific folders and examining the file modification dates and repeating this process for all other folders and files.

All of our participants also mentioned engaging in infrequent (ranging from once a week to three times a year) but repeated reflection activities throughout their design career to look at the progression of their design process, change in style, and refresh memories of success or failure, or reminiscence. 11 out of 12 participants mentioned engaging in reflection to get in the

"creative state of mind." As this type of reflective activity is not tied to any specific project, designers currently rely on their memory to explore *sought-after materials* from different potential projects. These sought-after materials can be physical (sketches stored in a sketchbook) or digital (final design, inspirational materials, etc.), however, we are observing a trend of designers transitioning towards digital materials. While all designers retained their sketch books, we also observed all designers scanning "preferred sketches" and storing these along with other project materials. In addition, while some designers, especially product designers and architects retained the physical models of preferred artifacts, they also captured and stored images of these models in the project folders.

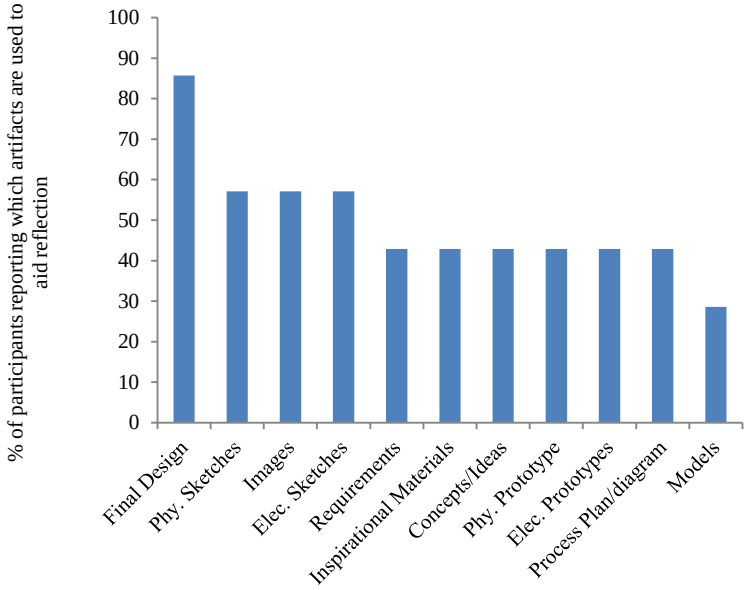


Figure 5.3: Use of different types of design materials during reflective activities.

Existing artifacts are an integral part of reflective activities. Figure 5.3 shows utilization of different types of artifacts during reflection. While artifacts act as cues for recalling design process, context, and rationale, over time they lose their effectiveness. Designers' perspective on a project and her design changes with time, but artifacts don't evolve to represent or capture this change.

5.2.3 Mapping of Reflection to Specific Design Activity

Table 5.2 lists questions designers try to answer while engaging in reflective activities and our mapping of these questions to relevant design activity. While these questions are

targeted to improve the quality of design outcomes, some are focused on gaining an overall understanding of the past designs, while others are targeted to specific projects or design tasks.

Number	Question	Activity
Q1	What was the design process for this project?	Exploration of artifacts
Q2	How did the project evolved? How it progressed with time?	
Q3	How did I come up with the final result?	
Q4	What types of inspirational materials/reference materials were used?	
Q5	Can I use artifacts, lessons, template from this project in a new project?	
Q6	What was the goal of this project and did the final design satisfy the goal?	
Q7	What did I learn from this task (project) and how can I apply these lessons in future? How can I improve this design/process?	Evaluation
Q8	Is it possible to change the direction of the project? What are the alternate approaches available for solving this problem?	
Q9	How can I replicate my successes and avoid failures?	
Q10	Am I making progress as a designer? Are my designs illustrating my style?	
Q11	How does this project compare with other similar projects, other projects?	Comparison
Q12	How does this project fit with my other projects?	
Q13	How much time it took to complete the project? Different phases of the project?	Comparison and Estimation
Q14	How much time it will take to complete a similar project?	

Table 5.2: List of questions frequently asked during reflective activities.

For example, Q1 through Q6 are targeted to learn about the overall design process, artifacts, and lessons for future projects while Q11 through Q14 are aimed to compare this current project with other similar projects. All these questions can be broadly mapped to four types of activities (exploration, evaluation, comparison, and estimation) that designers want to perform during reflection.

5.2.4 Challenges in Engaging in Reflection

Design projects typically involve many artifacts, including many variations of a concept or many versions of an artifact, each version containing minor modifications. Accumulation and exploration of all these artifacts to get an overview of the process or project is extremely difficult, if not impossible by using traditional file centric tools. Some participants mentioned utilizing descriptive naming and personalized organization to store artifacts that belong to a specific design phase. While this naming helps retrieval of specific types of artifacts, it fails to provide insight about the design context and flow of design activities. Gaining insight about the utilized process by examining artifacts is extremely difficult and requires a lot of manual effort and time.

Reflective activities often center on recalling design activity such as how much time was spent on concept generation, from when in the design process ideation began, when and how prototype was finalized, and what inspirational materials were used. However, existing systems offer very limited support for recalling high-level design activity, putting the burden solely on the designer to remember what happened, when and why it happened, etc. All designers expressed a need for better representation of artifacts and process that would allow access to such design information.

Study participants also commented on the difficulty to estimate effort and time invested on a project using current tools. They considered effort estimation almost impossible by looking at electronic artifacts stored in various directories and accessed by file management and navigation systems.

Overall, our study participants reported feeling challenged as file management and navigation tools are the state-of-art technology available for engaging in reflective activities, but provide almost no support for designers to achieve their goals surrounding reflection.

In chapter 6 we will describe the design of a new tool that will address problems associated with reflective activities.

Chapter 6

ReflectionSpace: An Interactive Visualization Tool for Supporting Reflection in Design

Based on the findings from our prior studies, we postulated that a visual representation of design artifacts that captures and communicates the design process and context of design activity would better foster reflection-on-action. To validate our approach, we designed, implemented, and evaluated ReflectionSpace, an interactive visualization tool for supporting activities associated with reflection-on-action. The key innovation in ReflectionSpace is that it maps existing design artifacts to appropriate design phases and contexts of use and places corresponding representations into a time- and activity-centric visualization that can be navigated at different levels of detail. ReflectionSpace aids designers engage in activities related to reflection-on-action, such as recalling their design process, constructing and communicating stories, and estimating effort in their design process. In this chapter we report the design and implementation of ReflectionSpace.

6.1 System Design Goals

Based on findings from the interviews discussed in chapter 5, we identified several key design features for a reflection support system:

1) Provide a time- and activity-based representation of design artifacts. The simple list of artifacts offered by existing file management and navigation systems makes it difficult to gain an overview of the design process. We chose to represent artifacts within a project utilizing their creation and edit histories and appropriate design phase. Artifacts are mapped to the appropriate design phase using file names, which can be configured by the end user. A local database containing information about projects and details about all artifacts utilized in the project is used to create this representation.

2) Support for exploring design artifacts in context of creation and use within the project. Design artifacts, particularly when presented in their context of use, provides stronger cues for recalling specific design stories.

3) Support for examining artifacts at different levels of detail. Designers want to get an overview of their overall design process, flow of design, effort invested, etc. Abstract representation of design activity using different time units, such as, day, week, and month, offers better insight of the process utilized and flow of design. It also provides insight about the underlying design activity and effort invested in various stages of design.

4) Support for visual comparison of projects. For analyzing process followed for different projects, designers need to be able to readily compare different projects in terms of artifacts created and used and effort invested overall and for the different phases of the projects.

5) Support for interacting with design artifacts to indicate preference and/or attaching comments, lessons, or rationale capturing thought processes along with the artifacts. Designers revisit preferred artifacts more frequently than others and want to examine past projects in terms of design milestones. They also want to capture feedback, rationale or reflective thinking along with the artifacts, but are discouraged by the associated overhead.

We designed and implemented ReflectionSpace as an interactive visualization tool to support activities associated with reflection-on-action. ReflectionSpace was designed through an iterative process. We shared early prototypes with local designers and addressed their feedback on subsequent iterations. The implementation was built using the latest version of the Processing language and visual C#.

6.2 ReflectionSpace User Interface

ReflectionSpace consists of a project view, compare view, and overview. Figures 6.1 (a, b, and c), 6.4, and 6.5 show the project view, compare view, and overview interface respectively. These representations are created based on an architecture project targeted to remodel a dome in the University of Illinois campus. The project goal was to redesign the dome as an amphitheater.

6.2.1 Project View

The project view interface creates a visual representation of a user selected project. Projects can be selected from a drop-down menu (containing names of all available projects) or from the overview interface (by clicking on the representation of a specific project).

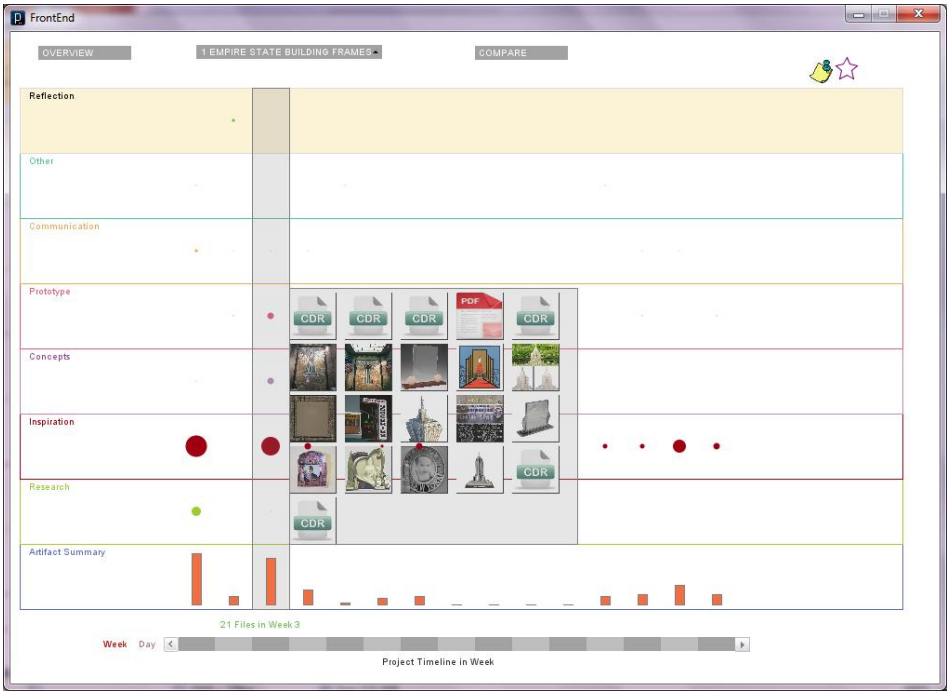
The project view interface structures the design process into five pre-defined channels representing activities pertaining to different design phases. The design phases represented are: research, inspiration, concept, prototype, and communication. We chose to include these phases as our discussion with designers about their design process suggested that these phases are typical for creative design projects, especially for the domains of graphic, web, industrial, and product design. Also, these channels are designed to encompass artifacts created with a specific design goal, in a specific design phase, or to achieve a specific objective. For example, the research channel contains all artifacts created and utilized in the research phase. These artifacts can be part of user research, artifact analysis, competitive testing, or come from behavioral mapping of place or user [4]. The inspiration channel contains any artifact that the designer created/collected as an 'inspiration' for the project. The concept channel contains artifacts created in the early design phases (e.g., sketches, post-it notes, ideas, etc.). The prototype channel on the other hand contains artifacts ranging from mockups, low fidelity prototypes, to final design. All types of communication are placed in the communication channel, which includes but are not limited to feedback received from clients and other designers, meeting minutes, requirements, and final presentation materials. In Figure 6.1 (a), the research channel containing materials related to lighting conditions and its potential impact on the observatory, the inspiration channel contains images of different types of domes that the designer collected, the concept channel contains early drawings of floor plans, the prototype channel contains her models created in autoCAD and images of physical models of the proposed design, and the communication channel contains prototype designs sent to her supervisor and the feedback received.

However, not all creative design projects will have artifacts belonging to all the above mentioned categories or may not follow the same design model or may have artifacts that do not correspond to any of the phases mentioned above. For example, the PRInCiPleS framework [72] presents the design process in terms of analysis and synthesis, where analysis combines all types of research and synthesis combines concepts and prototypes. While both PRInCiPles and the

process model in ReflectionSpace focus on similar types of design artifacts, the vocabulary used to represent them are different. As such, designers who organize and structure their artifacts more closely with the model used in ReflectionSpace, will have a better representation of their process. The "other" channel contains artifacts that do not correspond to the five phases listed above. The project view interface contains two additional channels - the bottom channel summarizing activity performed at a specific time period and the top "reflection" channel that provides a space where a designer can capture his or her reflective thoughts.

Figure 6.1 (a). ReflectionSpace UI (project view). Any project can be selected from the drop down menu (b). Design activity can be viewed at different level of abstraction by clicking time units (d and e). Time (f) is positioned along horizontal-axis while channels (g-m) representing different design phases are positioned along vertical-axis. (n) is the reflection channel where notes and stories can be added. (o) is the activity summary channel. (p) is the note-icon which allows adding notes to a material or in the reflection channel. (q) is the favorite icon which allows marking materials as favorites. Design materials are represented by the circles. (r) shows the thumbnails of all materials created in the selected day.

b) Day-view in Project view interface



c) Week-view with detail of a week's activity

Figure 6.1(b, c): Different representation of the project artifacts in ReflectionSpace.

In the project view, artifacts are represented as different colored circles. The color indicates the type of artifact (and design phase), including research, inspiration, concept, prototype, and communication. The design phases can be explored using different time units, e.g., day-view or week-view. The day-view creates a day wise activity representation of the project while the week-view offers a summarized view of weekly activities. Activity is computed using the number of artifacts created within the specific time period. Materials in both views are positioned using creation time (X-axis) and design phase (Y-axis) in different channels. Figure 6.1 (b and c) show day and weekly representations offered by ReflectionSpace project view interface.

While this mapping and positioning is automatic, this mapping may not able to categorize all the materials accurately. To empower designers to control the mapping and modify any 'incorrect mapping', the interface allows designers to easily change the mapping by simple drag-and-drop interaction. To re-map any artifact, the designer simply repositions the artifact from the current channel to the desired channel and this change is reflected in the interface and changed in the database. The time-axis at the bottom of the interface allows navigation for exploring any part of the project. In addition, placing the cursor over the time-axis provides details of the materials created at that time point. Placing the cursor over any circle representing materials provides thumbnail, filename, creation date, size, and location.

Designers believe that capturing short notes about design decisions, rationale, feedback from clients or others, even thoughts about an artifact's choice of color or design would be tremendously valuable. ReflectionSpace UI supports adding small notes and attaching these with the artifacts by using the "note" tool. Designers can add notes by clicking the "note icon" and then clicking a specific artifact with which the note will be attached. Once done, notes can be saved and retrieved later. Presence of a note with an artifact is reflected by a special marker on top of the circle representing the artifact.

Story telling is an important part of the creative design process. To support story construction, designers can use the "story" tool which provides a space where designers can reference one or more artifacts and enter an optional note. After a story is created, a story symbol appears in the reflection channel, which allows later retrieval. Figure 6.2 presents a story constructed using a graphic designer's artifacts.

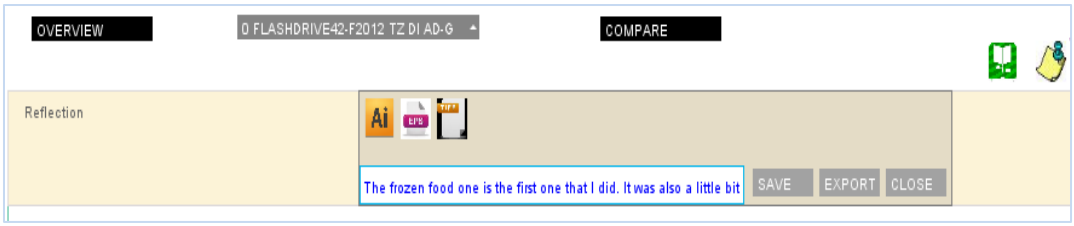


Figure 6.2: ReflectionSpace Story Construction interface (partial). This story contains three artifacts and a note.

To reflect effort invested in a specific design activity, we used filled and unfilled circles. The artifacts that are revised extensively (top 10% in a specific design category), are represented using unfilled circles while the remaining are represented using filled ones. Figure 6.3 presents artifacts from an architect's project; the concepts that are revised most are represented with "unfilled" circles to allow quick access. Our choice of contrasting filled and unfilled circles makes the most revised artifacts perceptually salient and easy to identify. Alternatively, to measure the actual time spent revising an artifact; we would have needed to instrument all the possible applications a designer uses to revise an artifact.

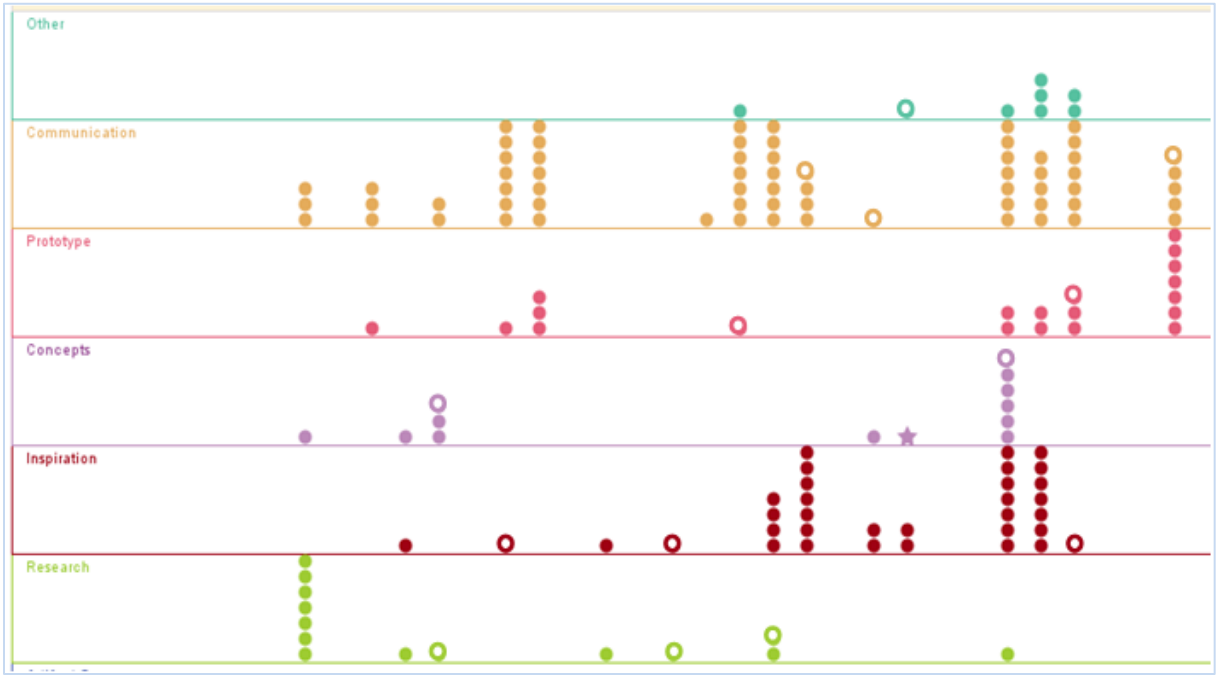


Figure 6.3: ReflectionSpace Interface showing 'most revised' artifacts.

However, this would become complex and challenging as a designer may open an artifact, perform edits, switch to other tasks (while the artifact in question is still open), and close the artifact at the end of a work day (without performing more edits). Also, our discussion with designers about their reflective goals revealed that they are more interested to learn about high-level design information (e.g., what were the artifacts where I invested most of my effort) rather than specific edit times.

6.2.2 Compare View

The compare view (see figure 6.4) renders a summarized representation of the projects, including each of the design phases, to enable comparison between any number of projects.

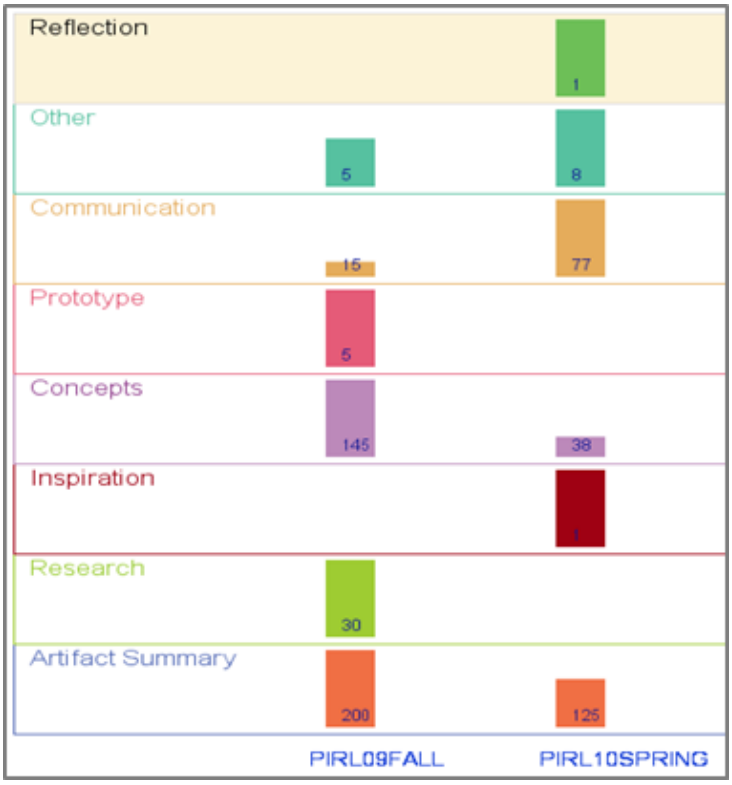


Figure 6.4: ReflectionSpace Compare view interface (partial).

Figure 6.4 presents comparison between two projects of a product designer. The project represented in the left was targeted to create a “compact home cleaning equipment” while the project in the right was on creating a “welding mask”. The compare view highlighted the

difference in the process utilized for both projects – project 1 (the home cleaning equipment) has nearly four times more concept than project 2 (welding mask), has research materials and prototypes (project 2 has none). On the other hand, project 2 has five times more communication than project 1. While unaware about this discrepancy, after reflecting, she attributed these differences to the complexity of the target products. She recalled that project 2 required communication with different stake holders (users who will use the mask, buyers who will make decision about buying a certain mask, and client who will actually pay for buying the equipment) while project 2 only required communication with the client. She also recalled the due to the extreme work conditions where the mask would be used; concept generation required careful examination of the constraints and requirements and didn't offer much freedom in the design. This limited the number of concepts generated for project 2, however, required more time to complete compared to project 1.

6.2.3 Overview

The overview creates a high level representation of the entire design space. In this view designers can see a time-based abstract representation of their projects. Each project is represented with a rectangle where width of the rectangle is proportional to length of the project (each small bar in X axis indicates a month). Projects are placed based on their start date (X-axis represents time in months). It is typical for designers to work on many projects in parallel and the Y-axis is used to position concurrent and overlapping projects.

Figure 6.5 presents the overview of all research projects completed between 2008 and 2013 for a researcher. This view highlights that it is typical for this researcher to work on multiple projects in parallel, projects can be of varying duration (three months to twelve months), there are recurring projects with a common theme (project names reveal that there are multiple projects for CHI, CSCW, and C&C). Representations such as this can be more beneficial for designers who can get an idea about their productivity (how many projects did I work on from September 2010 to September 2011), clients (how many projects did I complete for this client, how long the projects took), change in work style (am I working on less/more number of projects than before, are my recent projects longer than prior ones, what types of projects am I working on recently).

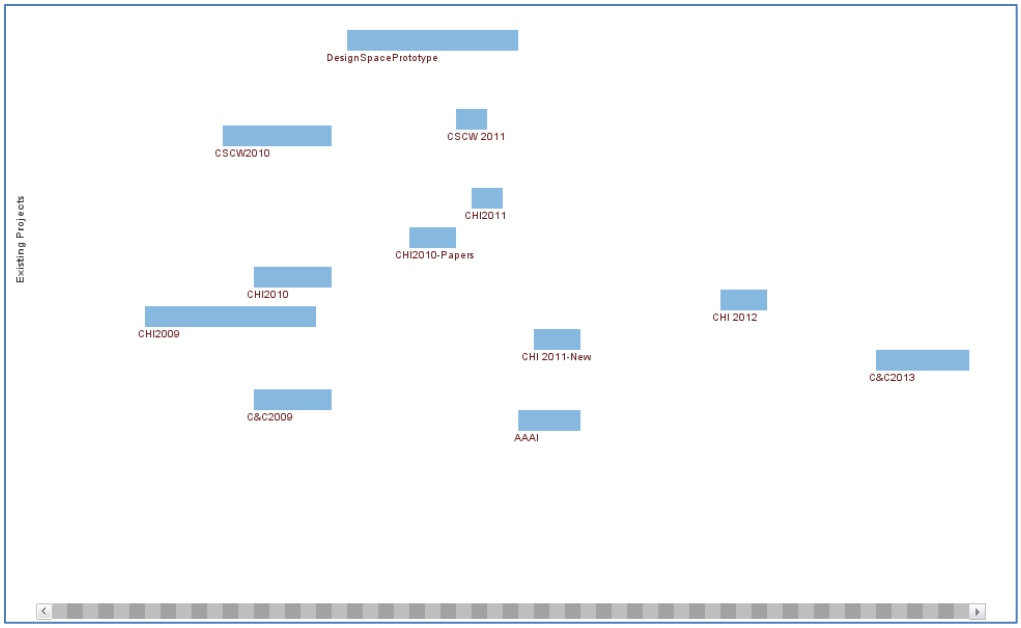


Figure 6.5: ReflectionSpace Overview interface (partial view). Projects are positioned using creation time and project length (X axis).

6.3 System Architecture

ReflectionSpace has two main sub-systems: a frontend containing the ReflectionSpace UI and content modifier, and a backend containing a desktop crawler and file information aggregator. File information aggregator has two components – information collector and content-mapper. ReflectionSpace UI communicates with the file information aggregator and the local database to create visual representations of the design materials. The content modifier tracks user interactions and communicates with the local database to capture and reflect the changes made by the user. The desktop crawler is responsible for collecting project and file information and their attributes, and for passing them to the file information aggregator. By "design space" we denote the electronic space consisting of all the folders and files in a designer's machine where she saved her artifacts. Figure 6.6 presents the system architecture of ReflectionSpace.

The file information aggregator extracts file information, creates thumbnails of the materials, creates mapping between files and design phases and stores file information in the database. The content-mapper utilizes user's file naming, organization, along with file type and creation date to automatically map materials to appropriate design phases. For example,

materials stored inside a folder named “sketch” gets mapped to concept phase. Desktop crawling and file information aggregation and mapping are executed continuously to collect information about file access.

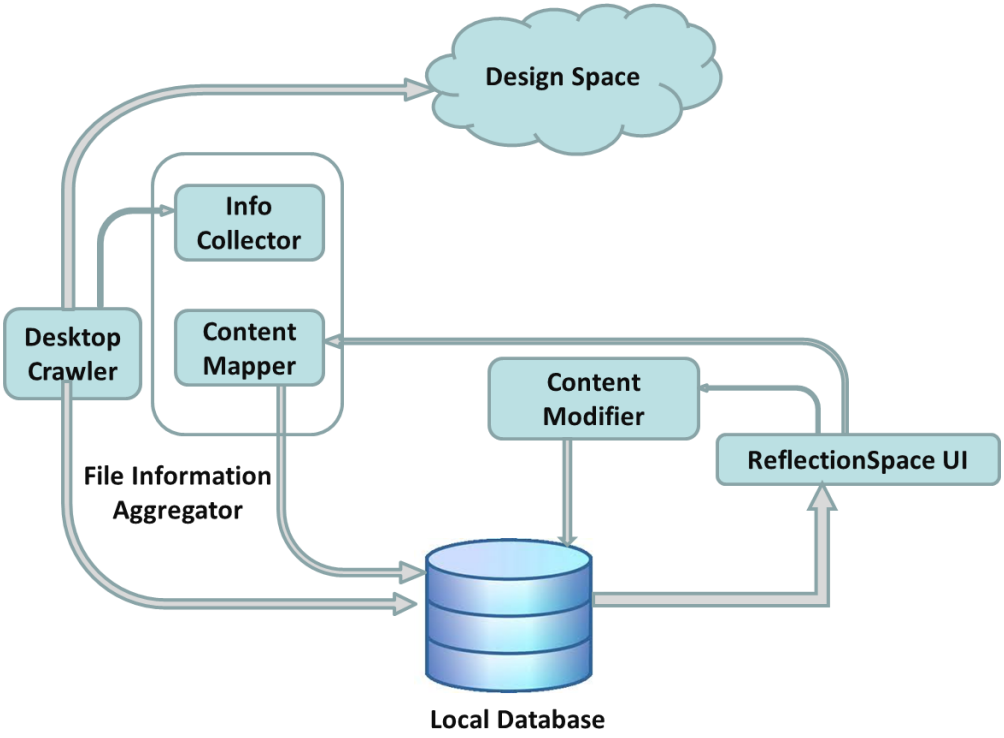


Figure 6.6: ReflectionSpace Architecture

6.4 Mapping Policy used in ReflectionSpace

To map individual files to appropriate design phases, we have first defined sets that correspond to the different design phases and sets of file_types corresponding to the different types of files typically utilized for the design phase. For example, to represent the prototyping phase, we have defined two sets, one consisting of the common terms utilized by designers to represent materials and activities associated with prototyping (prototype) and a second set consisting of the file extensions typically associated with files created for the prototyping phase (prototype_filetypes). We have defined the following categories and sets for mapping individual files to specific design categories:

Category = {{Research}, {Inspiration}, {Concept}, {Prototype}, {Communication}, {Reflection},{other}};

Research = {research, userresearch, usrresearch, analysis, background, phase0, phase 0, round 0, user, usr, userinterview, competitor, product, site, precedence, interview, documentation};
Research_filetypes = {{Doc_filetypes}, {Font_filetypes}, {Image_filetypes}};

Inspiration= {inspiration, sample, visual ref, reference, palette, color palette, font, example, ref};
Inspiration_filetypes = {pdf, html,{Font_filetypes},{Image_filetypes}};

Concept = {drawing, sketch, sketchup, illustration, diagram, concept, phase 1, idea, layout, site, siteplan, floorplan, schematic diagram};
Concept_filetypes = { ai, skp, skb, indd,{Image_filetypes}};

Prototype = {design, mockup, model, prototype, deliverable, final, phase 2, round 2, render, 3d render, AutoCAD, CAD, floorplan, siteplan};
Prototype_filetypes = {psd, cdr, dwg, dwf, ai, ctb, html, eps, skp, 3dm,3ds, dxf, plt, dst};

Communication = {media, inbox, outbox, fax, mail, email, e-mail, contract, invoice, billing, bill, requirement, presentation, communication, memo};
Communication_filetypes = {{Doc_filetypes}, {Presentation_filetypes}, qxd, edb, {Media_filetypes}};

Reflection = {lesson, notes, note, learning, pointer, rationale};
Reflection_filetypes = {{Doc_filetypes}};
Other = {database, brush, font};
Other_filetypes = {key, page, zip, xls, bak, log, fdb, f2k, exe, abr,{Font_filetypes}};

Font_filetypes = {ttf, otf};
Image_filetypes = {jpg, jpeg, gif, png, bmp, tiff};
Doc_filetypes = {doc, docx, txt, pdf}

Media_filetypes = {avi, mp3, mp4}
Presentation_filetypes = {ppt, pptx}

Creating sets to represent specific design phases is challenging because the terms designers utilize is not only domain dependent, but also dependent on individual designers' naming preference. For example, the early idea generating phase can be termed by a designer as phase 0, phase 1, round 0, round 1, ideation, concept generation, sketching, diagramming, and many variations of these terms. In addition, while graphic, web and industrial designers mentioned utilizing the term "concept generation" or "ideation", architects mostly referred to this phase as diagramming, or as schematic diagramming, which is more representative of the task they engage in. In this dissertation we defined a set of policies that maps artifacts to specific design categories. While this is a good start, we believe providing an interface that allows designers to create their own mappings would result in better categorization.

Following is a set of representative policies used for creating the mapping between specific files to appropriate design categories in ReflectionSpace:

$\forall$fileX $\text{fileX}_{\text{type}} \subset$ Prototype_filetypes $\Rightarrow \text{fileX}_{\text{Cat}} =$ Prototype … … … (i)
$\forall$fileX $\text{fileX}_{\text{name}} \subset$ Prototype $\vee \text{fileX}_{\text{dir\_name}} \subset$ Prototype $\Rightarrow \text{fileX}_{\text{Cat}} =$ Prototype … … … (ii)

$\forall$fileX $\text{fileX}_{\text{type}} \subset$ Image_filetypes $\wedge$ ($\text{fileX}_{\text{name}} \subset$ Research $\vee \text{fileX}_{\text{dir\_name}} \subset$ Research) $\Rightarrow \text{fileX}_{\text{Cat}} =$ Research … … … (iii)
$\forall$fileX $\text{fileX}_{\text{name}} \subset$ Research $\vee \text{fileX}_{\text{dir\_name}} \subset$ Research $\Rightarrow \text{fileX}_{\text{Cat}} =$ Research … … … (iv)

$\forall$fileX $\text{fileX}_{\text{type}} \subset$ Image_filetypes $\wedge$ ($\text{fileX}_{\text{name}} \subset$ Concept $\vee \text{fileX}_{\text{dir\_name}} \subset$ Concept) $\Rightarrow \text{fileX}_{\text{Cat}} =$ Concept … … … (v)
$\forall$fileX $\text{fileX}_{\text{name}} \subset$ Concept $\vee \text{fileX}_{\text{dir\_name}} \subset$ Concept $\Rightarrow \text{fileX}_{\text{Cat}} =$ Concept … … … (vi)

$\forall$fileX $\text{fileX}_{\text{type}} \subset$ Image_filetypes $\wedge$ ($\text{fileX}_{\text{name}} \subset$ Inspiration $\vee \text{fileX}_{\text{dir\_name}} \subset$ Inspiration) $\Rightarrow \text{fileX}_{\text{Cat}} =$ Inspiration … … … (vii)

$\forall$fileX $fileX_{name} \subset$ Inspiration $\vee$ $fileX_{dir\_name} \subset$ Inspiration $\Rightarrow$ $fileX_{Cat}$ = Inspiration … … … (viii)

$\forall$fileX ($fileX_{type} \subset$ Doc_filetypes $\vee$ $fileX_{type} \subset$ Presentation_filetypes) $\wedge$ ($fileX_{name} \subset$ Communication $\vee$ $fileX_{dir\_name} \subset$ Communication) $\Rightarrow$ $fileX_{Cat}$ = Communication … … … (ix)
$\forall$fileX $fileX_{name} \subset$ Communication $\vee$ $fileX_{dir\_name} \subset$ Communication $\Rightarrow$ $fileX_{Cat}$ = Communication … … … (x)

$\forall$fileX $fileX_{type} \subset$ Doc_filetypes $\wedge$ ($fileX_{name} \subset$ Reflection $\vee$ $fileX_{dir\_name} \subset$ Reflection) $\Rightarrow$ $fileX_{Cat}$ = Reflection … … … (xi)
$\forall$fileX $fileX_{name} \subset$ Reflection $\vee$ $fileX_{dir\_name} \subset$ Reflection $\Rightarrow$ $fileX_{Cat}$ = Reflection … … … (xii)

$\forall$fileX (($fileX_{type} \notin$ Doc_filetypes) $\wedge$ ($fileX_{type} \notin$ Presentation_filetypes) $\wedge$ ($fileX_{type} \notin$ Image_filetypes) $\wedge$ ($fileX_{type} \notin$ Media_filetypes) $\wedge$ ($fileX_{type} \subset$ Font_filetypes $\wedge$ ($fileX_{name} \notin$ Research $\vee$ $fileX_{dirname} \notin$ Research)) $\wedge$ ($fileX_{type} \subset$ Font_filetypes $\wedge$ ($fileX_{name} \notin$ Inspiration $\vee$ $fileX_{dirname} \notin$ Inspiration))) $\Rightarrow$ $fileX_{Cat}$ = Other … … … (xiii)

$\forall$fileX ($fileX_{type} \subset$ Image_filetypes) $\wedge$ ($fileX_{name} \notin$ Research $\vee$ $fileX_{dirname} \notin$ Research) $\wedge$ ($fileX_{name} \notin$ Inspiration $\vee$ $fileX_{dirname} \notin$ Inspiration) $\wedge$ ($fileX_{name} \notin$ Concept $\vee$ $fileX_{dirname} \notin$ Concept) $\wedge$ ($fileX_{date}$ < Concept_Start_date) $\Rightarrow$ $fileX_{Cat}$ = Research … … … (xiv)

$\forall$fileX ($fileX_{type} \subset$ Image_filetypes) $\wedge$ ($fileX_{name} \notin$ Research $\vee$ $fileX_{dirname} \notin$ Research) $\wedge$ ($fileX_{name} \notin$ Inspiration $\vee$ $fileX_{dirname} \notin$ Inspiration) $\wedge$ ($fileX_{name} \notin$ Concept $\vee$ $fileX_{dirname} \notin$ Concept) $\wedge$ ($fileX_{date}$ > Concept_Start_date) $\Rightarrow$ $fileX_{Cat}$ = Concept … … … (xv)

These policies are aimed at reducing the burden of manual categorization and organization of design materials to appropriate design phases. We have defined these policies based on results of our study where we asked designers to write down what they considered to be

the main steps in their design process and show us their current project folders to examine structures used their practice. We tried to capture designer defined steps in our created process model. However, as there are many types of design processes available [4], [73] and a designer can follow a particular process depending on the project, we believe that allowing the designer to configure the channels would result in better mapping.

In this chapter we have discussed the design and implementation of ReflectionSpace. In the next chapter, we discuss results from a comparative study that we conducted to investigate the efficacy of ReflectionSpace as a reflection support tool.

Chapter 7

Assessing the Effectiveness of ReflectionSpace for Supporting Reflection

In this chapter we report the results of a comparative laboratory study aimed to evaluate the efficacy of ReflectionSpace in supporting reflection. We were interested to learn in which ways ReflectionSpace supports reflective activities and whether ReflectionSpace offers better support for reflection compared to existing practice. The evaluation therefore explored how well ReflectionSpace supports activities designers typically engage in during reflection and how it compares with the use of a traditional file-centric representation, which is commonly used in design practice. Due to a relatively small sample size, we did not necessarily expect to see statistical significance and therefore only report statistical tests when significance was achieved.

7.1 Method

We followed a cued recall paradigm where we tested what could be recalled about a design project with and without ReflectionSpace and a traditional file-centric representation. Seven professional designers (3 female) from Graphic (N=4) and Architectural design (N=3) participated in the study. All had at least one year of professional design experience. Participants were paid $75.

There was one independent variable: the tool used for facilitating reflection (ReflectionSpace and File Explorer). The study used a within-subjects design. We collected electronic materials pertaining to two real-world design projects from each participant before the study. To reduce bias related to relative importance of different projects, we asked participants to select two projects with nearly equal importance, length, and recency. Materials collected from the participants were used to create representations in ReflectionSpace and File Explorer prior to the study. The representations using File Explorer were identical to what the participants sent, just created on a local machine.

The study was divided into two sessions. Each session consisted of a free recall test, followed by a cued recall test, and a post-interview. One session used ReflectionSpace for cued

recall while the other used File Explorer. The order of the sessions (tool used) was counter-balanced and the two projects from each participant were randomly assigned to the sessions. The two sessions per participant occurred on different days at least a week apart.

On arrival for the first session, the participant was provided general instructions about the study, received a brief demonstration about the tool used (ReflectionSpace or File Explorer), and participated in the free recall session. The participant was encouraged to provide as much detail as s/he could recall about the project. We used a set of questions in the free and recall sessions similar to the questions designers ask themselves while engaging in reflective activities (details about the questions frequently asked during reflective activities are discussed in chapter 5). These questions were targeted to learn about the project and details about each of the phases typical in a design project. In the second phase of the session, the participant was asked to answer the same questions about the same project but using either ReflectionSpace or File Explorer. The participant was allowed to explore the project materials as desired in the assigned tool and any other tool they wished to use and was asked to share any additional detail s/he could recall about the design process. Table 7.1 lists the questions asked during free- and cued-recall sessions.

Research Materials	
Q1	Can you talk about the different types of research materials that you collected for this project? (as many as you can remember).
Q2	How much time did you spend on collecting different types of research materials (such as user research, product research, etc.) for this project?
Q3	Can you specify the names of different sources from where you collected different types of research materials used in this project? (as many as you can remember)
Q4	Please discuss important lessons that you learned from this phase of the project and any important details that you remember.
Inspirational Materials	
Q5	Can you talk about the different types of inspirational materials that you collected for this project? (as many as you can remember)
Q6	How much time did you spend on collecting inspirational materials?

Table 7.1: Questions asked during free and cued recall sessions.

Q7	Please mention the names of different sources from where you collected inspirational materials. (as many as you can remember)
Q8	Please discuss important lessons that you learned from this phase of the project and any important details that you remember.
Concept/Idea	
Q9	Approximately how many concepts did you generate for this project? How much time did you spend on generating these concepts?
Q10	Can you recall artifacts that you utilized for generating the final concept?
Q11	What was your approach for selecting the final concept?
Q12	Please describe important lessons that you learned from this phase of the project and any important details that you remember.
Prototype/Model	
Q13	Approximately how many prototypes did you generate for this project? How much time did you spend on prototyping?
Q14	Can you recall artifacts that you utilized for generating prototypes?
Q15	If you created multiple prototypes, how did you select the final prototype?
Q16	Please describe important lessons that you learned from this phase of the project and any important details that you remember.
Overall Design Process	
Q17	How much time did you spend for completing this project?
Q18	Please discuss significant design points of this project.
Q19	Please discuss important lessons that you learned from this project and any important details that you remember.
Q20	How did this project compare with your other projects in terms of time spent, artifacts collected and created, prototypes generated, etc.?

Table 7.1 (Continued): Questions asked during free and cued recall sessions.

In the last part of the session, we interviewed the participant to gauge his or her overall perceptions of the tool used for reflection. Table 7.2 lists the post-interview questions. The process was then repeated for the second session using the other tool. In addition, to gauge user

opinion about the effectiveness of ReflectionSpace in supporting reflective activities, we requested our participants to rate ReflectionSpace and its features using a 5-point Likert scale. See Table The7.3 for a list of questions used for collecting user rating.

Question Number	
Q1	What features of FE/RS you consider to be most effective for engaging in reflection, if any? In which ways these features support reflection?
Q2	What features of FE/RS help you to recall your design process, if any? In which ways these features help you to recall your process?
Q3	What lessons do you recall/learn about your past project by using FE/RS? What features of FE/RS help you in this process and how?
Q4	What features of FE/RS help you to estimate effort invested, if any? What features of FE/RS help you in this process and how?
Q5	What feature(s) of FE/RS helps you to compare different projects, if any? In which ways these feature(s) helps you to compare your projects?
Q6	What feature(s) of FE/RS helps you to get an overview of all your design projects, if at all? In which ways these feature(s) helps you in this process?
Q7	What features of FE/RS you consider to be ineffective or prohibitive for engaging in reflection, if any? Please explain why do you consider these features to be ineffective?
Q8	What is your overall opinion about FE/RS as a reflection support tool? What features of FE/RS do you like and why? What features do you dislike and why?

Table 7.2: Post-interview questions.

Question Number	
Q1	How effective is the project view interface in helping you to recall your design process?
Q2	How effective is the compare interface in helping you to compare between two projects?
Q3	How effective is the categorization of design materials provided by ReflectionSpace?
Q4	How effective is the project view in helping you to recall and communicate your design story to others?
Q5	How easy is it to recognize/identify your artifacts using ReflectionSpace?
Q6	How easy is it to get an overview of your project using ReflectionSpace?
Q7	How useful is the project view interface for identifying progression of a project?
Q8	How useful is the project view interface for identifying time-spent on the different phases of a project?
Q9	How easy is it to understand the information provided by ReflectionSpace?
Q10	How easy is it to access (see thumbnail, open the material in its own application window, etc.) artifacts using ReflectionSpace?
Q11	How easy is it to estimate time-spent on a project using the project view interface of ReflectionSpace?
Q12	How easy is it to change the categorization of an artifact using ReflectionSpace?
Q13	How effective were visualizations provided by ReflectionSpace in helping you to notice/recall things about your project that you didn't/could notice/recall?
Q14	What is your likelihood of using Reflection Space for your projects?
Q15	How would you rate ReflectionSpace as a reflection support system?

Table 7.3: Questions aimed to gauge opinion about ReflectionSpace.

7.2 Results

7.2.1 Overall Ratings

Table 7.4 summarizes participant ratings of different features of ReflectionSpace (RS) as a reflection support tool. During the study sessions with File Explorer, when asked about its effectiveness as a reflection support tool, all of our participants mentioned *only using File Explorer due to an unavailability of better tools*. They also commented that File Explorer was not designed to support reflective activities and as such while helpful for organizing their files, it is not effective for reflective activities. As a result, they chose not to rate File Explorer and its features as a reflection support tool.

Metric	Average Rating	Standard Deviation
Overall rating	4.0	0.63
Visualization to recall design process	4.3	0.52
Ability to compare projects	3.8	0.75
Effectiveness of content-mapping	4.3	0.52
Support communicating design story	4.7	0.52
Identify/notice hidden patterns	4.3	0.82
Ease of recognize/identify artifacts	4.0	0.00
Effectiveness of getting overview	4.0	0.89
Ease of use of features	4.8	0.45
Understand progression of project	4.0	0.89
Understand time invested in a project	4.5	0.84

Table 7.4: Ratings of ReflectionSpace as a reflection support tool (5 point Likert-Scale, 5 is best).

Table 7.4 shows that our participants considered ReflectionSpace (and its features) effective, useful, and easy to use. All of the study participants stated that they see themselves using this system regularly and expressed interest in continued use (average rating was 4 / 5). Table 7.5 contains ratings about different features of ReflectionSpace and File Explorer. The

ratings reported in Table 7.5 were obtained during the cued-recall sessions by asking our participants to indicate whether and to what extent a certain feature was supported by a tool (5= excellent support, 0= no support at all). For example, we asked our participants to rate the effectiveness of File Explorer in aiding project comparison.

Feature		**Average Rating (AVG) and Standard Deviation (SD)**			
		RS		**FE**	
		AVG	SD	AVG	SD
Process visualization	Time-based visualization of design process	4.6	0.55	N/A	N/A
	Day-view of design process	3.8	0.45	N/A	N/A
	Week-view of design process	4.4	0.55	N/A	N/A
Automated mapping of artifacts	Automated file mapping	4.2	0.84	N/A	N/A
	Drag and drop to change mapping	4.8	0.45	N/A	N/A
	Color-coding of files based on design phase	4.4	0.55	N/A	N/A
Interaction with artifacts	Mouse clicks for opening files	4.4	0.55	5.0	0.0
	Ability to mark artifacts as favorite(s)	4.0	0.7	N/A	N/A
	Mouse-hover to see details of an artifact	4.8	0.45	5.0	0.0

Table 7.5: Ratings of different features of ReflectionSpace and File Explorer.

All participants expressed frustration with current file management and navigation systems for supporting reflective activities and considered most of the features unsupportive (see Table 7.5). They only considered current systems slightly better than ReflectionSpace for accessing files and viewing different size thumbnails (ratings for RS are 4.4 and 4.8 while ratings for FE are 5 and 5 respectively). Our participants mentioned using file management and navigation systems during reflective activities due to a lack of better technology. However, after

using ReflectionSpace, participants used words such as “Nice!”, “wow!”, “love it!” and “Impressive!” and commented on its usefulness as a reflection support tool.

Participants found the interfaces offered by ReflectionSpace innovative, engaging and useful. One designer commented that *“this interface looks like a designers’ representation of a project”.* During the study, participants spent most of their time exploring artifacts positioned in different channels and narrating *“what occurred at that time”.*

All the participants explored a number of different types of artifacts and shared the context of use of these artifacts. They also opened up several artifacts from different stages of the project to make sure that the system correctly placed these artifacts. They were impressed with the automated mapping (average rating 4.33/5) and wanted to know more about the algorithm used for content-mapping. Knowing that the mapper utilizes file naming and organization among other information, three out of the seven participants also stated that they feel more encouraged to be more careful in naming and organization as it would result in better mapping.

One goal of reflection-on-action is to experience “the unexpected” and six out of seven participants mentioned that they were “surprised” by noticing patterns in their process which they didn’t even know existed (average rating 4.33/5). Participants also liked the visual representation of the design process and the different level of details that can be accessed when necessary. To quote our participants:

“I believe the potential of this tool could become essential to my design process.” – P7

“This (ReflectionSpace) is better. Even for one project, you can visualize it. In case of file explorer, you have open different folders and files to realize a project. A graphical representation surely helps.” – P3

“It’s easy to have an overview of the project and describe why we have a lot of work in the beginning and less work in the end. And also I think the mouse hover is very nice. You can hover on them and you can directly see an overview and get an idea of on what phase I was on at that moment. It’s just like directly tell you about structure of the story of what happened on that project. I have never seen this type of interface exist in the market and I think it will be really helpful for the designers.” – P6

In the following section, we report our findings from the free- and cured-recall sessions along with the post-interviews. These findings are collectively drawn from participants answers to questions listed in Tables 7.1 and 7.2.

7.2.2 ReflectionSpace Aids in Recalling Design Process

ReflectionSpace provides a time- and activity-centric representation of the project materials. This representation was liked by all the participants as it highlighted the flow of design activity and provided better access to the context of design (average rating was 4.6/5). During the study,, participants explored different types of artifacts positioned in different channels from different parts of the project (using different times from the time-axis) and commented on how this representation *"makes perfect sense"* and *"accurately reflects"* what was going on at that time. Several of the participants also wanted to examine if their artifacts are represented in the *"right"* time and phase. Examining a thumbnail of an image file placed in the research category, participant P7 at a first glance considered it "*misplaced*", but after opening up several other closely positioned files, he recalled the context where he used this file. He stated:

"I sent this image to my subordinates the same day the project was initiated so that they can use it. When I just looked at this, I thought I used it later in the project, but after seeing all these, now I remember. It's great." - P7

This representation also allowed designers to see the progression of their project and where they have invested their time.

7.2.3 Representing Design Activity in Different Level of Detail Helps in Estimating Effort Invested

ReflectionSpace highlights designers' activities by displaying all materials collected, created, and utilized in a project at various levels of detail. Designers can see all materials created in a day or in a week such as all of their research materials or prototypes created. ReflectionSpace also makes the most revised artifacts (top 10% within each channel) more noticeable than others. Our participants commented that such representations are very valuable as they highlight the amount of work completed in a specific time interval (day or a week).

Figure 7.1: Weekly representation of a graphic design project. The designer is exploring different types to artifacts created at different times to examine his effort invested and change in his design focus.

In addition, they liked such representations as it showed the types of work completed with the progression of the project, highlighting the changing focus of the designer. Figure 7.1 presents an abstract representation of a projects activity in terms of artifacts created. This representation highlights where in the project the designer focused on a particular type of design activity. It also presents the flow of the project. For example, figure 7.1 shows that for this eight weeks project, this designer only actively created new artifacts for four weeks, with one very high activity week and two very low activity weeks. It also shows that the designer started working on the research materials early, from the beginning of the project. The designer began generating concepts and prototyping from the third week and also shared his design with the client. The only activity for the remaining weeks were refining the prototype and sharing the design with the client. Designers preferred the week view of the project materials over the day-view (user rating 4.4/5 and 3.8/5 respectively) for not only estimating effort invested but also to understand the flow of their project. To quote a designer:

"I think it has the potential to help me understand where I am spending my time during my design process" – P5

Designers considered this depiction effective not only for understanding "*time spent*", but also for *"planning"* and *"billing".* It is common for designers working in the design firms or in design teams at organizations to work on multiple projects concurrently and it is expected that they manage their time well and balance their effort invested. It is even more important for freelance designers as effective estimation of time is essential for billing the client. While necessary, traditional file centric approach doesn't help designers to track or estimate their time easily. Designers mentioned trying to utilize commercial project planning software (basecamp: [74]) or time trackers (Manic Time: [75]) without much success. While these commercial systems provide information about total time spent, they require tremendous amount of manual work (finding out times spent on design related applications) to extract information about how much time was spent on a specific application (such as Photoshop), but fails to provide project specific breakdown of information. The visualization provided by ReflectionSpace though doesn't provide specific numbers about total time spent, it shows them when and where they have spent their time on different levels of detail and is also tied to specific design projects. The following quote exemplify designers' preference and opinion about ReflectionSpace:

"It is interesting to see how much time I spent on each of these phases. As a freelancer, it is nice to know for future projects about how much time I can spend on each phase, so when it is time either to bid the job or to bill, I would know how much, so that would be very valuable there." – P7

While participants considered our use of time invested in editing to be a close approximation of the overall effort invested, one designer considered this feature somewhat lacking (while the average rating is 4/5, she gave it a 2/5). She felt that the system should make some provision for assigning the value manually to reflect the time spent on editing the materials and/or the related cognitive effort.

7.2.4 Effective Communication of Design Story

The visual representation of the artifacts provides better support for recalling and communicating stories about the process followed, decisions made, and sources utilized. The following two are considered as "stories" (both stories are shared when designers were interacting with ReflectionSpace):

"The frozen food one (QuadShop-FrozenFood.ai) is the first one that I did. It was also a little bit different because it was gonna be produced as a backlit, in another word that was going on the freezer here, I took a picture of it. This one (IMG_3634.jpg). That's the first one I made and that's where all the coloring get right. That was produced in because it is different than printing on regular paper than on foam core. Once we got further than frozen food, then everything else kind of easier then." – P7

"These are initial items (small-logo-with-white-blue-orange.gif), these are initial things that I designed and you can see there are some elements like I mentioned the slanted text, didn't like that, and then the same idea, repeated the idea and then I repeated the same concept, I put it as a logo in a circle, so if you see here there's a circle on that one (small-logo-with-white-blue-orange.gif), and there's not a circle on this one (small-logo-blue-orange.gif), he was like, I don't like circles, I don't want to put my logo on a circle. He was really worried about his logo and that's why I ended up redoing the logo anyway." – P1

Figure 7.2 show the change in the design of the logo in the web page. The designer recalled the story about creating many versions of the page without much success and finally learning from the client that he doesn't like the logo design in the top left corner, which resulted in rejecting all the pages.

Figure 7.2: Slight variation in the two versions of the web page. The design of the logo (top left corner) was changed based on clients feedback. The designer recalled the story of this transformation while accessing materials using ReflectionSpace.

We observed designers following two distinct strategies for exploring materials using File Explorer and ReflectionSpace. While using File Explorer, designers opened more than half of the folders that they have created for the project. Designers explored materials stored in these folders and when asked about the motivation, they answered that the folders were created for mimicking their design process and they were expecting to recall more details about their design activity by exploring these materials. While materials stored in the folder named "FINAL" or "INSPIRATION" helped designers to retrieve materials used for a specific design phase, it didn't provide access to the context of design.

We also observed that designers, who create specific naming strategy for their folders, deviate now and then from these strategies, especially at the end of the project. For example, folder named "PIRL Final" contained a subfolder named "1" and the files stored inside these folders had the default naming (images taken during evaluating the product) and the "final" design was stored in a folder named "PIRL sc". This created difficulty for the designer when she was trying to reflect using the File Explorer as it took her several unsuccessful tries to find the right material. Also, to avoid a situation where one file may belong to multiple folders (when folders are created for holding files related to specific design activity), some designers create

multiple copies of the file and store these in multiple places. However, if one of these files get updated, that change is not reflected in the other copies and designers trying to reflect end up digging through materials in multiple folders trying to find the most updated version. One designer who explained how her folder names always contain information about the *client* and *time of creation (PIRL1021 refers to PIRL as the client, October 21st)*, during study we found that she has many folders that not only deviates from this naming convention, she is also unaware of using folder names that doesn't conform but also had little idea about why she used a certain name. This created a problem during reflection as she had to explore almost all the folders and materials to find a needed material. Figure 7.3 shows that five out of seven participants opened up more than half of their project folders for finding needed materials and recalling design stories.

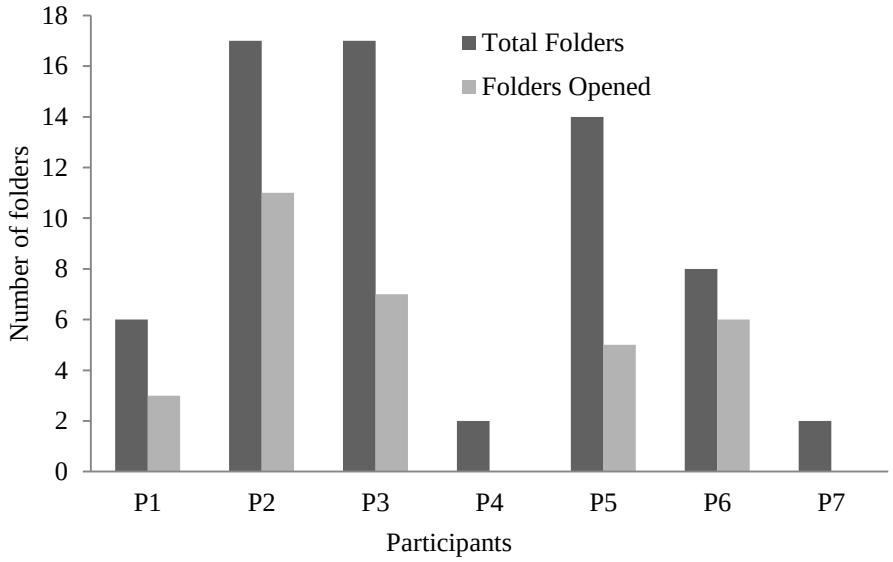


Figure 7.3: Total number of folders explored during study (cued-recall session).

Also, designers who believe they have folders created for specific type of design materials such as sketches or inspiration or final materials, end up having other types of files stored in them. Designers acknowledge the need and benefit for creating and organizing their materials meaningfully and value meaningful organizations, however, they find it challenging to maintain this strategy even for small projects.

In ReflectionSpace, since materials are positioned based on their creation time and respective design phases, materials displayed in the same vertical line indicate what types of artifacts were created within a week or at the same day. Our participants explored materials positioned in close proximity and were able to recall context of creation and use of these materials. They commented on the effectiveness of such representation and how it offered better support for recalling design stories (average rating 4.67/5).

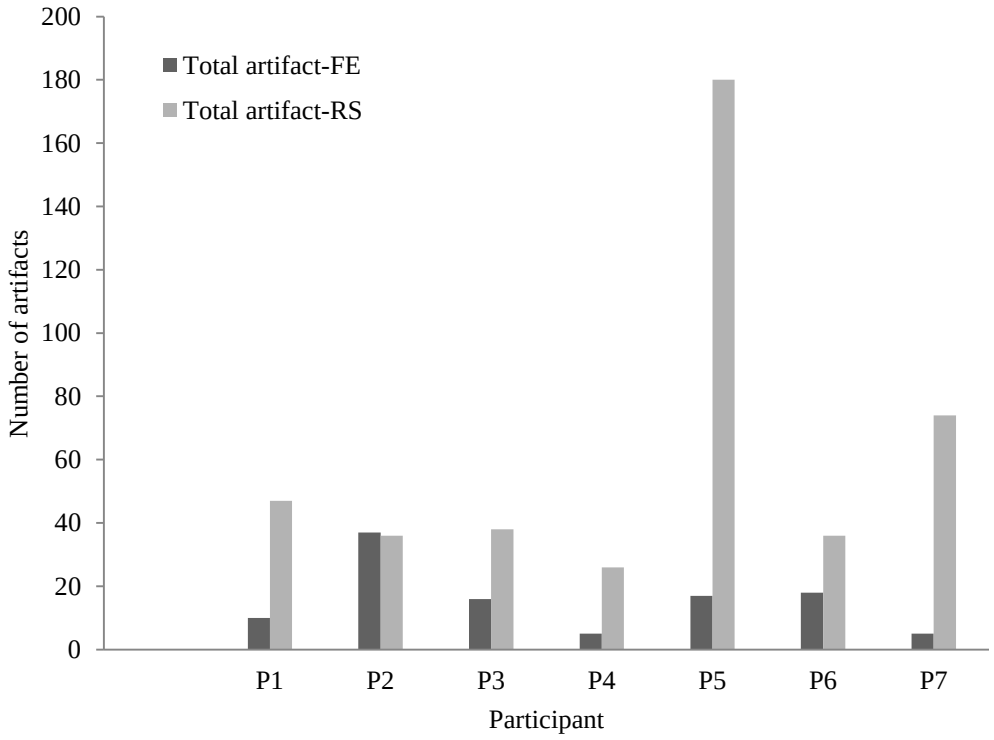


Figure 7.4: Total number of artifacts explored using File Explorer and ReflectionSpace. Designers explored more materials using ReflectionSpace compared to File Explorer.

In addition, exploring materials related to a theme or materials that were used for generating a particular concept acted as memory cues and designers were able to get a glimpse of "what they were thinking at that time." Overall, our participants explored more artifacts (marginally significant) using ReflectionSpace (M=62.43, SD=54.03) than when using File Explorer (M=15.43, SD=10.97; $t(6)=2.24$, $p=0.06$) (see Figure 7.4 for total number of artifacts explored). While asked about their motivation for exploring artifacts, designers commented on

how a group of relevant artifacts helped them to get an idea about what was actually happening at that time. Looking at an artifact in isolation often failed to convey the reason for utilizing the material, sometimes it was confusing for the designers as they were unsure about their motive. However, materials placed in close spatial proximity allowed them to get better idea about their work process.

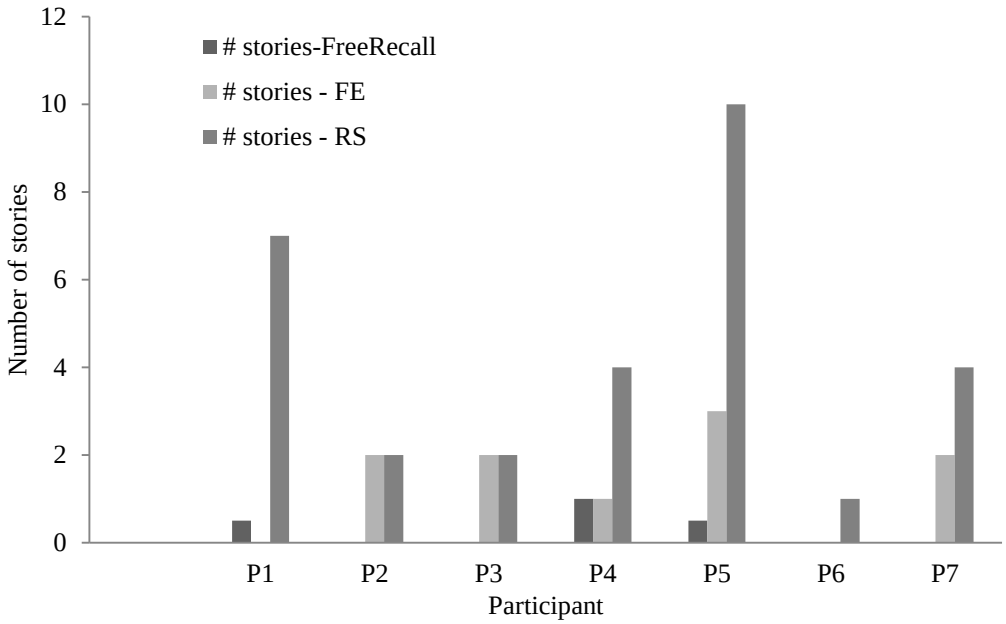


Figure 7.5: Total number of story recalled and shared from memory, using File Explorer and ReflectionSpace.

We expected that participants would be able to recall and share more stories (see chapter 5 for our definition of 'story') about their project during the cued-recall sessions (using a tool) than free-recall session (from memory). Five out of seven participants shared significantly more stories using ReflectionSpace than File Explorer or from memory. The remaining two participants shared equal number of stories using both ReflectionSpace and File Explorer. Every participant shared at least one story using ReflectionSpace, while two participants didn't recall and share any story using File Explorer and only four of seven participants were able to recall and share their design story from memory. Overall, our participants shared significantly more stories when using ReflectionSpace (M=4.29, SD=3.2) than during free recall (M=0.56, SD=0.79; t(6)=3.42, p=0.014. The number of stories recalled using File Explorer was also

significant (M=1.43, SD=1.13) relative to free recall (M=0.14, SD=0.38; t(6)=2.71, p=0.03). In addition, participants recalled more stories using ReflectionSpace (M=4.3, SD=3.2) than when using File Explorer (M=1.43, SD=1.14; t(6)=2.5, p=0.04). See Figure 7.5 for total number of stories shared by our participants.

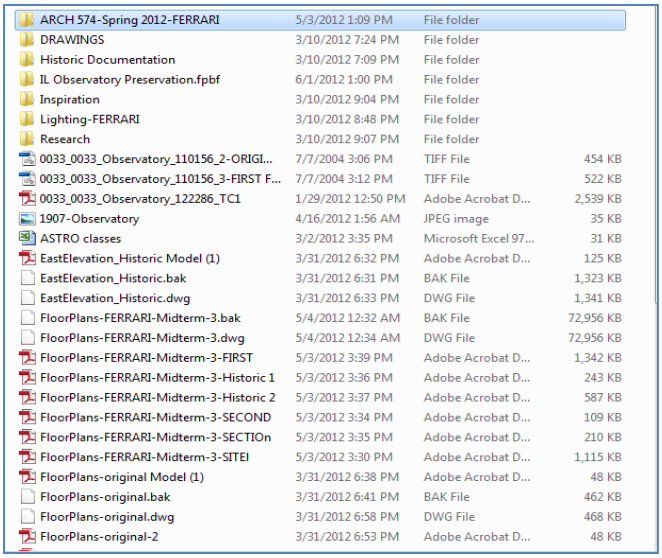


Figure 7.6 (a): Representation of a project in File Explorer.

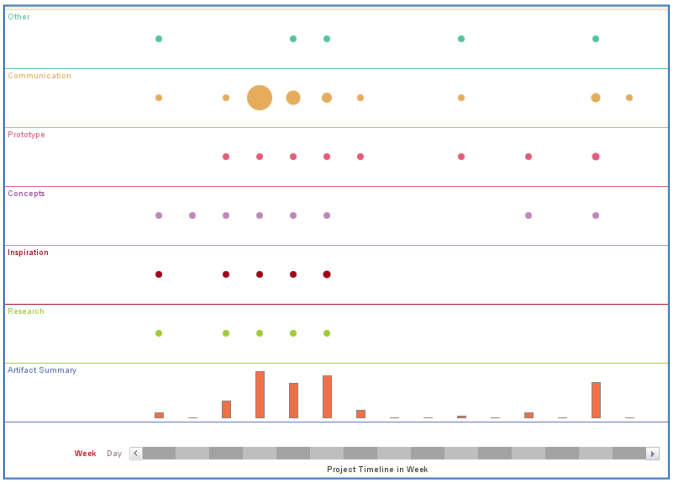


Figure 7.6 (b): Representation of the same project in ReflectionSpace (b). FE provides a linear list of filenames and attributes (size, creation date, and type), which offers no support for understanding the design process. RS, however, makes the design process visible by highlighting occurrences of specific design activity, time spent on different design phases, shifts in design focus, and periods of activity and inactivity.

As stories include details about a specific design activity, artifact, or rationale, designers were able to recall more stories when they had access to the artifacts. This signifies the importance of computer supported tools in supporting reflective story telling. In addition, our participants also were able to share more stories using ReflectionSpace as they could not only access an artifact, but also were able to access other artifacts created at that time, which provided better context.

All of the participants also commented that while the use of specific naming of directories and files helps them to group similar materials and to recognize different types of artifacts, it doesn't help in recalling the underlying design process and as such fails to assist in recalling the design story. Figure 7.6 (a) shows a representation of a project of participant P5 by File Explorer and Figure 7.6 (b) shows the same project with ReflectionSpace. After exploring both representations, she commented that despite using descriptive naming for folders to group similar types of materials, File Explorer didn't provide any insight on her design activity. However, representation offered by ReflectionSpace enabled recalling her process including different milestones and progression through the project.

7.2.5 Examining Design Process to Uncover Hidden Patterns

ReflectionSpace assists designers in examining their design process by offering different types of representation of the design activities. For example, designers can identify their active and inactive periods and also in which type of design activity they were engaged in at a specific time. They can also identify shifts in design focus by looking at where they started prototyping or if they utilized inspiration materials late in the design process. Our participants considered this very valuable as it offered new insight into the design process and helped *"sudden discoveries."* It also highlighted interesting patterns in ones work that the designer was unaware of (6 out of the 7 participants mentioned that the representations helped them to notice things that they didn't notice before). For example, after looking at a project representation (Figure 7.7), participant P1 noticed several long inactive periods between design iterations and after examining the materials realized that the inactive periods resulted from communication delays. He stated:

"It is almost embarrassing to see how long that project took, but it's good to see that. It's embarrassing because I can't believe I let it go that long. At the same time, (if I can share this

screen with my client) I can have that chat with my client and say, "hey, Steve, this is what happened. How can we change it for the next time to make the process better?"" – P1

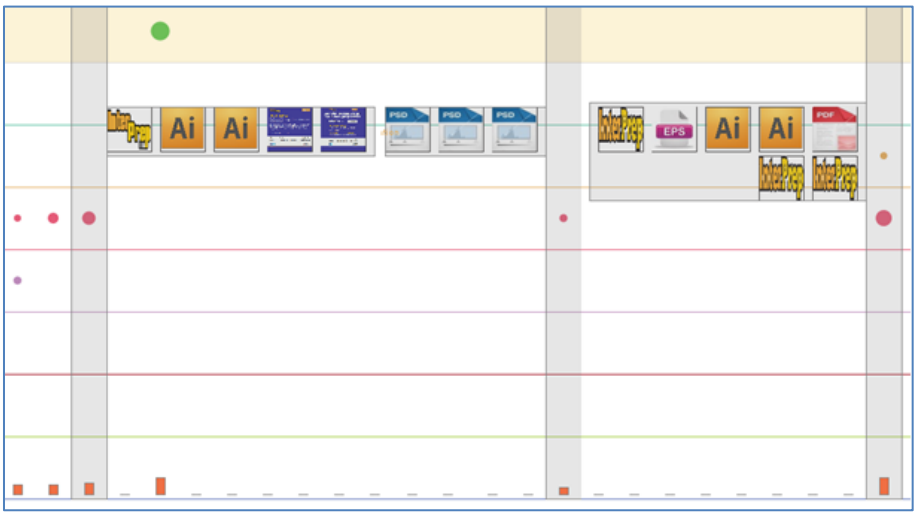


Figure 7.7: Partial representation of a project showing periods of design inactivity.

7.2.6 Effectiveness of Automated Mapping of Artifacts

ReflectionSpace automatically maps artifacts to a set of predefined design phases such as research, inspiration, and concepts. This is done to reduce the burden imposed on the designers for importing prior projects at first use. All of our participants considered the mapping effective, commenting on how it freed them from coming up with appropriate categories or placing a material in the perfect directory. Six out of seven participants rated the effectiveness of mapping as 4/5, with the remaining one giving it a 5/5. To quote a designer:

"Overall it did a great job at categorizing and all that. Most of the things are exactly where they should be." – P7

Designers also loved the ability to change any mapping with drag and drop (average rating 4.8/5) and commented that *"it is one less thing I have to categorize or be concerned about."-P5*

Though the default mapping was effective, it is possible to configure the available categories and the rules for mapping files (based on file naming conventions) to the categories.

7.2.7 Free versus Cued Recall

Figure 7.8 presents time spent by our participants reflecting on their projects during both sessions and using both tools and from memory (we only have session 2's data for P1). Time spent is the sum of all times designers spent on answering the questions listed on Table 7.1. The first two bars represent time spent reflecting on project 1 and the second two presents time spent reflecting on project 2 (these projects were randomly assigned). See Figure 7.9 for average time spent from memory and using the tools.

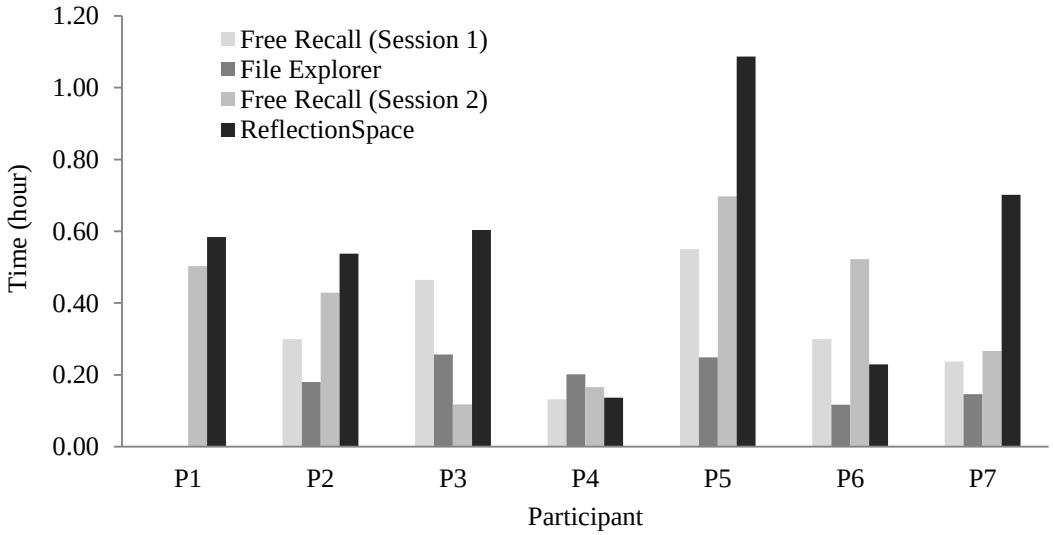


Figure 7.8: Time spent during the study sessions reflecting on a project (4 sessions).

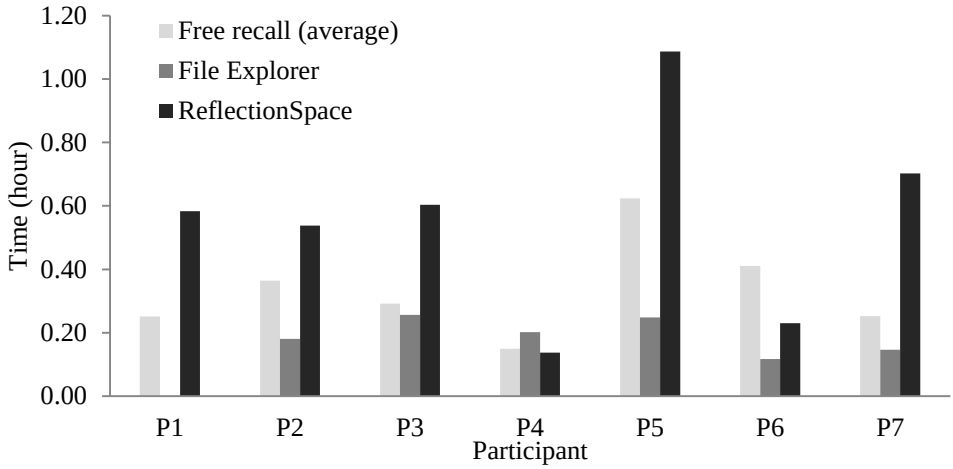


Figure 7.9: Time spent during the study sessions reflecting on a project (on average).

We expected that participants will be able to recall more details about their projects during cued-recall session versus free-recall session (using File Explorer and ReflectionSpace vs. memory). We noticed overall time spent varied greatly with individuals (e.g., P5 spent on an average 4 times more time than P4 in her free recall sessions). When comparing time spent by individual designers reflecting on their own projects, we observed that five out of seven participants spent the most amount of time using ReflectionSpace. Interestingly, all participants except one spent more time reflecting in the free-recall session (from memory) than using File Explorer. Participants commented that while File Explorer allowed them to access individual files to see the details (e.g., color and font used and creation and modification dates), it didn't help in recalling additional detail about their design process, context, rationale or stories. Instead, during the study sessions, almost all participants used File Explorer to confirm their statements shared during the free-recall session. This is also evident from the lower number of stories recalled by our participants using File Explorer (see Figure 7.5).

7.3 Discussion

We have investigated the efficacy of ReflectionSpace in a lab study with experienced designers. Our automated mapping of design materials to the different design phases was considered effective. ReflectionSpace aided designers in recalling design stories as well as design context and assisted in estimating effort invested. It also helped them to identify hidden patterns and interesting anecdotes, and enabled them to compare different projects.

ReflectionSpace currently utilizes default categories to group artifacts, but allows reassignment of the artifacts, if needed. This automated mapping and support for easy re-mapping was considered useful by our study participants. However, training the system to learn from designers' modifications may result in a more effective and personalized mapping of the artifacts. For example, if a designer changes the mapping of all "qxd" files to the category "communication" irrespective of their name, the system could learn and apply this mapping to all current and future files with this extension. This would also allow the designer to personalize the mappings over time.

Currently, ReflectionSpace does not allow designers to examine a partial set of artifacts and their context. Instead, it provides a representation of all activities for in-context exploration

at different level of detail. However, we found for some artifacts, especially those deemed 'memorable,' designers may not want to explore the project or its process, but only want to explore the artifact in question and its surrounding context. Allowing designers to define the time window(s) which will be the focus of the representation may offer better support for some reflection scenarios.

In our study, we asked designers to participate in free and cued recall tests to learn about the relative benefits of a visualization of design process for aiding reflection. It would be interesting to evaluate ReflectionSpace through a longer-term deployment in designers' own work environments.

Chapter 8

Discussion and Future Work

In this chapter, we discuss issues related to the design of ReflectionSpace, issues related to the evaluation of the tool, and also provide guidelines for better design support tools based on our experience of building ReflectionSpace. We also discuss future directions.

8.1 Effectiveness of Content Mapping

Every designer is unique and has a personalized way of organizing and naming her artifacts, which often represents her mental model of the design process. ReflectionSpace takes advantage of designer's own organization and naming conventions by defining a set of flexible rules for mapping the artifacts stored in the local file system to create the visualization of the tool. It maps artifacts to specific design activities considering file names, file extensions, folder names, and folder hierarchy. The mapping rules were defined a priori by inspecting naming conventions and organization observed in the study of reflective practice (study described in chapter 5). For example, AutoCAD is used for creating models and prototypes and as a result, artifacts created using AutoCAD are mapped to prototyping. The effectiveness of such mapping partially depends on designers' organization style and naming strategy. For example, for designers whose artifacts are better organized and have well-defined names (e.g., QuadShopSigns-OrderForm.pdf vs. xxBulkxx.ai) will have a better categorization in ReflectionSpace.

The current implementation of ReflectionSpace utilizes a pre-defined set of categories to map artifacts to different design activities. While designers found this categorization useful and were able to relate to the design activities they represented, during the evaluation study we learned that our categorization is slightly skewed to a specific design domain. For example, our use of the term "prototype" has slightly different meaning for graphic and product designers than architects. While architects could understand what type of design materials are categorized as "prototypes", they mentioned preferring terms such as "model" or "3D model" for the final/near final designs.

Providing designers with a default set of categories that can be modified and extended along with allowing designers to define their own mapping will alleviate such problems and also enhance the effectiveness of ReflectionSpace.

8.2 Visualizing History of Refinements

ReflectionSpace offers a time and activity-centric representation of the artifacts, where artifacts are positioned based on their creation times and design phases. This representation highlights association between artifacts using temporal proximity. Designers refine their artifacts based on feedback from other designers and client, inspired by other artifacts, or just by following their intuition. ReflectionSpace represents each artifact in its final form (e.g., mouse-hover will show a thumbnail of the final file and mouse-click will open the final file in its appropriate application window) and doesn't show the refinement history of a specific file.

While reflective activities often focus on understanding high level design information and doesn't require examining such details, in some scenarios it might be beneficial to be able to explore the revision history and its surrounding context. While some research prototypes ([32], [33]) and commercial systems (version control systems) capture every revision made to an artifact, these systems are not very helpful for supporting reflection as they disregard the context which influences the revision and also doesn't allow gaining high level understanding of all the artifacts or the overall process. One primary barrier in visualizing such activity traces is a lack of system support (current operating systems do not store revision history, they only store last access information). Systems can be developed that track revisions made to all artifacts and revision times, however, that would require instrumenting every possible application that a designer might use for accessing/revising the artifacts. A potential solution to this problem would be to take a semi-automated approach where a designer could specify a set of artifacts for which revisions will be tracked and stored. Alternately, not all artifacts get revised frequently and not all revisions are significant. Capturing only the significant revisions may lower the associated overhead. However, further understanding is needed for designing systems that would offer effective representation of such refinement history.

8.3 Supporting Project Comparison in Different Level of Details

ReflectionSpace offers comparison between projects based on types of design activity. While this comparison was well-received by our study participants, a few designers expressed interest in comparing ongoing projects with past projects at a finer level of detail. Designers felt that it would be tremendously beneficial to be able to compare an ongoing project's progression with a similar past project using weekly, monthly, or even using a daily view. Such comparison would allow them not only to examine and adjust their focus on specific types of activity, but also enable them to communicate their process to the client and set goals for themselves – using ReflectionSpace more as a planning tool.

Designing representations that allow comparison of "similar" projects is challenging as similarity can arise from a number of dimensions (e.g., same client, same product, same target user, etc.). As such, comparing *similar* projects requires further understanding of the factors that need to be represented and how to optimally represent them.

8.4 Learning from Designer's Interaction

ReflectionSpace categorizes artifacts based on organization, naming, and file meta-information (e.g., file type, date of creation, last access, size, etc.). This categorization is "soft" as designers can change it with a simple drag and drop interaction. Any designer-initiated change is permanent in ReflectionSpace and gets reflected in future representations of the artifact. However, this change can only be applied to a single artifact at one time as the current implementation doesn't support changing the category of a "group of artifacts" with a single click.

ReflectionSpace considers "designer initiated change" as atomic and the mapping algorithm doesn't learn from this interaction. For example, if ReflectionSpace categorizes an ".eps" file as a communication file and if the designer changes this categorization by moving the file to a new category, ReflectionSpace assigns this new category as the file's category but doesn't learn from this behavior. The other ".eps" files remain in their original categories. While this behavior limits any incorrect assignment of file category, it would be beneficial to ask designers whether they want to propagate this change to other files with the same file extension.

8.5 Long Term Evaluation of ReflectionSpace

We have evaluated ReflectionSpace in a lab study to gauge user reactions to the tool and probe how it affected their ability to recall their design process. However, a lab study has limitations, especially for evaluating reflection which may be sporadic.

A better indicator of the effectiveness of reflection support tools would require a long term deployment of such tools in designers own environment. We think that it would be interesting to see the results from a study conducted during the entire lifecycle of a project. Such a study will allow us to learn how designers are using this tool, how frequently and how long they are engaging in reflective activities, what features are they utilizing during these reflective sessions, and how such tools are influencing the design process and outcome.

8.6 Other Factors to Consider for Understanding Association between Artifacts

In this dissertation we focused on representing artifacts using time of creation and their associated design phase. Such representations indicate potential association between artifacts as related artifacts have higher probability of getting created and/or accessed in close temporal proximity. Our evaluation also suggested that such representations provide better support by helping designers recall 'what happened at that time.' Temporal proximity provides an approximation of a materials' association, however, it does not capture other rich information such as utilization of artifacts from other sources (e.g., browsing inspirational materials from Web, looking at a design magazine).

Provenance of materials can provide useful information about relatedness as suggested in [76], [77]. Research in the area of provenance primarily investigated relation among different types of documents by examining version history and occurrence of copy-paste events. We extend this thread of research by exploring relation among artifacts that were accessed at close temporal proximity. . For example, visiting design blogs and creating bookmarks while accessing a sketch file may point to relatedness among them. While promising, defining the 'optimal time span' that will be able to indicate such relation would require further investigation.

Researchers have also proposed systems that allow designers to manually assign relations among materials by utilizing spatial positioning [9]. While manual assignment ensures accuracy

of the relatedness assignment, this approach is very time-demanding and requires a lot of time investment from the designer. Our early study suggested that such costs are one of the main barriers that hinder reflection.

8.7 Future Work

Understand Social Aspects of Reflection

In this dissertation we have investigated individual designers' practices surrounding reflection-on-action and concentrated on artifacts created or collected by the designer. Design is rapidly transitioning to become a more open, collaborative process where reflecting on other designers artifacts will soon become a norm. Supporting reflection in this changing environment will require understanding of how designers access and utilize others' artifacts differently than their own ([78], [79]). Identifying factors that influence not only access and sharing of design information, but also how designers as a group make sense of others' processes and artifacts will help designing tools that would make reflection on shared materials successful, or even possible. In particular, we are interested in exploring what role ownership of information plays and how we can design representations that facilitate reflection on these shared materials.

Explore how designers react to automated content mapping

To be able to extract benefit from any automated system, it is important that users have an understanding of the algorithm utilized by the system [80]. ReflectionSpace utilizes a semi-automated content mapping algorithm to match artifacts to appropriate design activities. Effectiveness of such automated systems should be evaluated by investigating how well designers perceive the underlying algorithm and whether they are trying to embrace this mapping by modifying their existing practice. In particular, we are interested in exploring if designers change their organization and/or naming strategy in response to the algorithm used in the system – e.g. to ensure better mapping of artifacts to associated design activity. Early evidence observed in our evaluation study indicates that this may happen. For example, we found designers were rethinking their naming strategies to enhance the accuracy of mapping. Being able to understand the underlying mechanism of an intelligent system is important so that designers can adapt their behavior to extract maximum benefit.

Explore techniques for representing numerous design materials

For supporting reflective activities, it is necessary to provide access to a large number of artifacts in different levels of detail. Representations that provide access to all the artifacts allow designers not only to gain high level understanding of the underlying design process, but also to examine details when necessary. The underlying assumption for this type of representation is that all artifacts are equally important. However, design projects contain numerous artifacts, sometimes even in the scale of thousands and creating a representation that enables access to all the artifacts becomes challenging. Exploiting visualization techniques such as zoomable user interfaces (e.g., proposed in [81]) may offer a solution to this problem. However, ZUIs don't capture temporal order well [82]and even with ZUIs, due to the limitation of screen real estate, it is imperative to identify artifacts that would provide better access to the underlying design process.

Chapter 9

Conclusion

The goal of this dissertation was to design, develop and evaluate an interactive visualization tool to better support reappropriation of information in the creative design domains. Our work has made the following contributions.

First, we have provided further understanding of the practices of and attitudes toward information reappropriation during the early stages of design in the creative domains. Our work provides empirical evidence supporting prior theoretical postulations that use of prior knowledge is critical for design success. We also provide details about designers reuse practices, strategies utilized and challenges faced in this process. Our findings are distilled into actionable implications for the development of effective reuse support systems. Though not exhaustive, applying these implications can move this class of system closer to real-world adoption and we believe such systems have immense potential for improving design efficiency and the quality of design outcomes.

Second, we reported how the motivation and nature of information reuse varies in the creative design domains and can be better characterized as 'reappropriation.' We have demonstrated that reuse needs are centered on gaining an overall understanding of the design process, including recalling story, estimating effort, comparing projects, and getting inspired. These findings highlight the need for systems that will provide access to such high level design information as opposed to search and information management systems for supporting 'reuse.' Tool designers can leverage these findings as a set of guidelines for designing next generation reuse support systems.

Third, we have examined the process and practice of reflection-on-action, one of the core activities that prompt reappropriation. Reflection-on-action has a large influence on creative design allowing designers to critically think about the entire project, yet it has received little attention in prior work. This dissertation contributes to this thread of research by providing new understanding of designers' activities and needs associated with reflection-on-action. The key contribution of this phase of work is understanding details of designers' reflective behavior and

associated design activities, which can be leveraged for designing effective reflection support tools.

Fourth, we contribute the design of ReflectionSpace, a novel interactive tool for supporting reflection-on-action through a visualization of design process. Our design is motivated by designers' reflective practice, their needs surrounding reflection-on-action, and literature on design and creativity. ReflectionSpace uses file meta-data and naming conventions to map existing design materials to the appropriate design phase and context of use and places corresponding representations into a time- and activity-centric visualization that can be navigated at different levels of detail. This semi-automated mapping of design materials to corresponding design phase reduces burden of information organization, categorization, and tagging.

Finally, we provide results and insights from an evaluation of ReflectionSpace in a lab study with professional designers. Our findings provide evidence of effectiveness of interactive visualization systems in supporting reflective activities. ReflectionSpace aided designers in recalling design stories as well as design context and assisted in estimating effort invested. It also helped them to identify hidden patterns and interesting anecdotes, and enabled them to compare different projects. The central idea of making design process and context visible resonated with designers wanting to explore their materials for reflection. This indicates that designers would likely embrace the use of interactive visualization systems such as ReflectionSpace in practice.

Through the design, development and evaluation of ReflectionSpace, our work provides evidence of the efficacy of interactive visualization systems in supporting reflection-on-action as well as reappropriation of information in the creative design domains. The outcomes of this dissertation highlight the impact of design process visualization and opens up many new avenues for future research in the domain of design, reflection and creativity support tools.

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