Design Rationale: The Rationale and the Barriers

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ABSTRACT

One goal of design rationale systems is to support designers by providing a means to record and communicate the argumentation and reasoning behind the design process. However, there are several inherent limitations to developing systems that effectively capture and utilize design rationale. The dynamic and contextual nature of design and our inability to exhaustively analyze all possible design issues results in cognitive, capture, retrieval, and usage limitations. In addition, there are the organizational limitations that ensue when systems are deployed. In this paper we analyze these issues in terms of current perspectives in design theory and describe the implications to design research. We discuss the barriers to effective design rationale in terms of three major goals: reflection, communication, and analysis of design processes. We then suggest alternate means to achieve these goals that can be used with or instead of design rationale systems.

Author Keywords

Design rationale, theories of design, interactive systems design.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Design, as we define it in this paper, is a goal-oriented process aimed at solving problems, meeting needs, improving situations, or creating something new or useful 13Design rationale is the reasoning and argumentation that underlies the activities that take place during the design process. Design rationale tools are intended to support various design activities. In upstream design activities, where vague requirements are translated into concrete system specifications, Design rationale schemas are intended to provide a framework with which to carefully *reflect* upon design decisions. Structuring design arguments also is intended to provide a mechanism by which people with different goals can *communicate* their positions on design issues. It is also intended that people outside of the context of design, such as those involved in maintenance or redesign activities can use the documentation produced to aid in the *analysis* of decisions that have been previously considered. The intent is that this information can also be an aid in building a cumulative base of design knowledge, which would be a useful learning tool to both students of design and practicing designers 31

Design rationale systems are primarily intended to support *communication, reflection, and analysis* in design. Our motivation in writing this paper is derived from two questions that we would like to answer. First, since we don't have a common understanding of what *design* is, how can we have a common understanding of what *design rationale* is? Second, why is the collection of papers that describe Design rationale systems so much larger than the collection that describe DR successes?

In this paper, we will first consider design perspectives, and then turn to some obstacles that prevent design rationale systems from being successful. Finally, we suggest directions for future research in design rationale.

DESIGN PERSPECTIVES

Design rationale systems are intended to support people in the design process by allowing designers to share, structure, and record their thought processes that drive the tangible actions of design. In order to understand how design rationale can aid in the design process, it is important to understand current perspectives in design theory. There is no universally accepted definition of design within the broader design community 2We briefly describe some of the diverse views below.

Symbolic Information Processing

Herbert Simon 32viewed design as symbolic information processing and humans as goal-oriented information processors. He argues that design involves devising courses of action aimed at changing current situations into

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preferred ones. This broad view of design includes, as Simon states, "the core of all professional training." Design is viewed as a process of generating and navigating through a state-space. He argues that people do not, and cannot, consider all possible conditions, alternatives, and constraints, and therefore cannot design an optimal course of action. This cognitive limitation he termed *bounded rationality* 32Rather than exhaustively considering design issues, people choose satisfactory solutions based on the information available.

The argumentation structure of design rationale is argued to provide a natural framework in which designers can reflect on decisions. This structure can help focus the search for design alternatives, making cognitive processing more effective. Although designers cannot consider all possible alternatives, if rationale is recorded, maintainers will better be able to identify which ideas were deliberated upon. Reviewers who are working on different projects may identify important issues that they would not have otherwise considered. And, students and researchers could assess the impact of design decisions based on the outcome of a design activity.

Wicked Problems

Rittel and Weber 27dissented from Simon's notion that design could be represented as a state-space, stating that planning problems are "wicked problems." They list several reasons why planning problems are wicked problems, including the lack of a definitive formulation, stopping rules, or definitive measures of success. They also argue that each problem is essentially unique in certain aspects and state there are not an *enumerable* set of potential solutions. Moreover, discrepancies in wicked problems can be explained in many ways, and the choice of explanation determines the nature of the resolution. In other words, different people will look at a single problem in different ways, and the way the problem is represented determines how the solution will be derived. For this reason, design can be viewed as an argumentative process aimed at coming to a collective understanding of how to explain a problem.

IBIS (Issue Based Information System) was developed by Rittel as a means to structure this argumentation. In this sense, design rationale is intended to support collaborative design among designers with differing goals and perspectives. The structure afforded by design rationale provides a mechanism for designers to communicate their diverse thoughts with other designers working on the same task.

The primary benefit of design rationale from this perspective is that it can act as a collaborative communication tool. The unique nature of planning problems would present a potential barrier to the re-use of design rationale by students of designers and persons working on other projects. Still, the design rationale record could be used as a communication tool between initial designers and later designers or maintainers, who may have different views than the initial designers.

Situated Action

Schön 28describes design as a reflective conversation with the environment and suggests that designers reflect on what they are doing in the *action present*. The action present is a term used to describe a time when the effects of an action can still be influenced. This *reflection-in-action* allows people to design based on the feedback that is received during the design situation.

Schön notes that designers are most inclined to reflect on their activities when reaching breakdowns or when receiving unexpected feedback from the environment. Designers in familiar situations may not see a need to capture their rationale as they are routinely going though their design process, especially if it interrupts the efficiency of the process. During these breakdowns, design rationale can help designers reflect on what may have resulted in the problem. Tracking the associated design rationale would help communicate issues to future designers who may run into a similar problem. However, the designer's cognitive energy will be focused on understanding the situation and resolving the problems when these breakdowns occur. It is therefore important that if design rationale is used to support reflection, the effort in recording these aspects are minimal.

Incremental formalization 30is the process of gradually translating informal rationale into formal notations. Incremental formalization allows designers to easily capture design rationale in the act of designing, and later come back and formalize the information into a design rationale schema. Incremental formalization allows designers to both reflect in the act of designing and also communicate their rationale.

Systems that support a more efficient design process by making solutions easily apparent could reduce the amount of reflection involved in the design process. Therefore, it is useful to consider whether design rationale systems should support efficient identification of solutions or reflective understanding of the problem.

Patterns

Alexander 1describes the utility of patterns in design, which can be thought of as common solutions that resolve conflicting tendencies. He describes successful patterns in the architectural domain as "timeless" solutions that resolve the contextual forces in a given area. Alexander focuses on identifying the common quality of timeless solutions and suggests creating a "pattern language" that can be used to design artifacts that fit into the surrounding environment.

Patterns provide solutions, but designers may not be satisfied to trust that a given solution will work in a context without understanding the underlying reasons. And, recognizing why a pattern successfully resolves conflicting forces apparent in a given environment can help give early insight into the success or failure of a given solution. However, Alexander argues that patterns depend on stability, not purpose 1In other words, the logic of why a solution should work is not as important as what solutions tend to fit in a given context.

This suggests that applying design patterns requires both a thorough understanding of the context and a set of "timeless" solutions that work in these contexts. In the architectural domain, it is possible to look back thousands of years and identify patterns that seem to fit into a given context. However, in software engineering, solutions have typically only been around for a few decades. And, because of the rapidly changing advances in technology, there are few solutions that can be considered stable.

Creativity

Candy and Edmonds 6describe creative work as less predictable than routine work and look at how computer systems can support creative knowledge workers. They argue that systems meant to support knowledge workers should aim to reduce constraints imposed by these systems. This suggests that the constraints associated with design rationale systems could affect the effectiveness of creative workers using such systems. Kidd 19notes that knowledge workers have a very low dependence on filed information because they cannot reliably say when or how they will use a particular piece of information. Therefore, they internalize information so that it can be used in any possible future. Kidd concludes that people cannot predict what will inform them or how, and systems should not attempt to understand the information it is holding or predict how it will be used. These findings suggest design rationale systems may not be useful for effectively communicating creative knowledge.

Socio-technical Systems

Vicente and Rasmussen 34characterize events into three categories: familiar; unfamiliar, but anticipated; and unfamiliar and unanticipated. They describe the difference between these events and the effect on system users. Specifically, system operators typically have a considerable amount of experience with familiar events and are able to routinely deal with them; however, they state that people in familiar situations are susceptible to slips (i.e. errors of execution). On the other hand, people in unfamiliar situations are more prone to mistakes (i.e. errors of intention). They further explain that unfamiliar events that are unanticipated by designers are inescapable, and require improvisation on the part of the operator. Designers in familiar situations may not see a need to capture design rationale as they are routinely going though their design process, especially if it interrupts the efficiency of the process. On the other hand, in unfamiliar situations, designers' cognitive energy will be focused on understanding the situation and resolving the problems. And, recording design rationale could interrupt the design thought process, resulting in inadequate solutions.

Implications

A cursory analysis of these diverse perspectives on design helps to clarify the theoretical underpinnings of potential design rationale benefits, and also illuminate several potential barriers that impede the effective utilization of rationale. Table 1 summarizes the benefits and barriers to using design rationale that can be inferred from the previously described design perspectives.

Table 1. Pluses and Minuses of Design

Perspective	Value of Design Rationale	Potential Barriers
Symbolic Information Processing	DR can focus cognitive energy clearly on the options to be considered and their evaluations.	Bounded rationality means that all options might not be considered. Those not considered initially may be considered by later designers.
Wicked Problems	Facilitate a common understanding during collaborative design.	Wicked nature of planning problems present barriers to using DR at a different time or in a different project.
Situated Action	DR can help designers reflect on what decisions contributed to a breakdown. Incremental formalization could support the goals of both reflection-in-action and communication.	Using DR to identify solutions could result in less reflection. And, intrusive DR capture can hinder reflection on problems as they arise.
Patterns	DR provides a mechanism for designers to understand the problem context.	Because of the rapid advances in software engineering, there are few *stable* design patterns.
Creativity	Using DR formalisms may help designers internalize information that will be helpful in the future.	Constraints associated with using DR systems can hamper creativity.
Socio-technical Systems	Focusing on DR may help designers better understand unfamiliar situations.	Recording DR will interrupt the design process, resulting in inferior solutions.

DISCUSSION

Overall, Design rationale systems are primarily intended to support *communication, reflection, and analysis* in design. Norman 24describes the importance of bridging users' gulfs of execution and evaluation in designing systems. The gulf of execution is the gap between what a user wants to do with a system and the actions the system supports. In design rationale systems, it is important that designers can *easily* capture the reasons behind their design decisions so that other designers can recognize and utilize the information. To bridge the gulf of execution, it is important that the systems emphasize ease of use and appropriate representation of information. The gulf of evaluation refers to the ability for a system to provide a means to recognize whether the need has been met. Because of the asynchronous nature of design rationale systems, and the dynamic and unpredictable nature of design, it is often impossible for a designer to evaluate the utility of information entered into the system. This inherent problem with design rationale systems is one reason for the lack of success.

Design rationale systems are often intended to communicate the rationale behind design ideas to those outside of the design context. However, there are several potential areas where the capture and use of this information could be hindered. Figure 1 presents a conceptual model depicting the cognitive and physical path of design rationale from one designer to another.

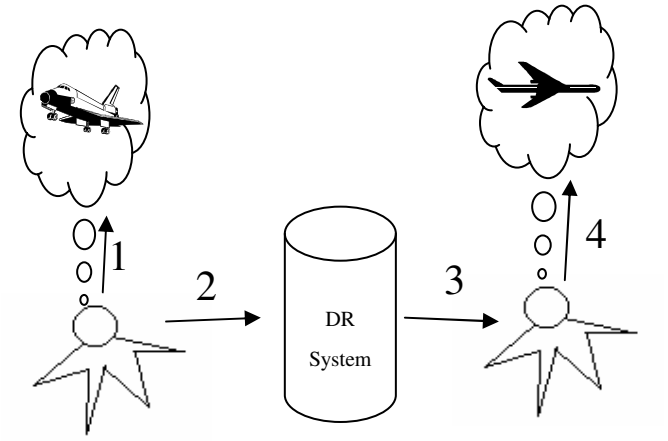

Figure 1. Potential Roadblocks to Rationale Usage

The figure is only a model of flow of information and does not depict many aspects of design, including the collaborative nature of design on both sides of the system and the numerous concurrent activities typical in design environments. However, the model adequately illustrates several limitations. We categorize these limitations into four groups corresponding to the numbered pathways of information.

1. Cognitive Limitations
2. Capture Limitations
3. Retrieval Limitations
4. Usage Limitations

There is also an additional aspect that must be considered, and it is one that is difficult to show in Figure 1. This aspect concerns the limitations imposed by the organization. So, to the list, we add a fifth category

5. Organizational Limitations

Cognitive Limitations

People have a limited capacity to process information. This limitation can hinder the effectiveness of design rationale. Simon 32states that we are bounded by our rationality and cannot consider all possible alternatives. Therefore, people choose satisfactory rather than optimal solutions. Since we are bounded by the amount of information we can process, design rationale is necessarily incomplete.

What Wasn't Considered

It is important to recognize the potential for unintended consequences, especially in systems where the risks are high 33In these situations, designers may want to ensure that they have exhaustively covered the design space so as to minimize the risk for unanticipated effects. The key question in this type of query is "what are we missing?" Design rationale is a potential solution to help designers identify issues that they may have otherwise left unconsidered. Systems could allow designers to search for similar projects or issues to identify issues that were considered in those projects.

Added Complexity

One mechanism to more exhaustively analyze the design space is to use collaboration in the design process 11However, in any collaborative design context, maintaining conceptual integrity is important to keep the design project focused 4More people are capable of considering more ideas, but this adds complexity and effort in keeping persons on the design team up to speed. It also increases the effort of integrating diverse perspectives.

Simon 32also notes that we are unable to exhaustively consider all possible alternatives, so we choose options that are satisfactory. Even if design rationale can effectively elicit additional issues, designers will not be able to spend more time reflecting on each issue. It is important that design rationale be used to help designers think about the right issues. In some situations, reflecting on the *why* aspects of design can help identify better alternatives; however, in other situations, it may be better be spend time thinking about what options are possible.

Capture Limitations

There are many different situations in which design rationale may not be captured. In some cases, the omission is unintentional. In others, it is quite intentional. We consider both below.

Capturing Rationale in Context – Unintentional Omission

Design rationale may be considered, but unintentionally not recorded by the capture process. There are several reasons why considerations could be unintentionally omitted from design rationale. If the design rationale capture takes place outside of the design process, it is possible that contextual cues may not be present, and designers may not recall what they deliberated upon, or designers may not be available at the time the rationale is captured.

For these reasons, it would appear that rationale should be captured in the context of design. However, it is not always possible or advantageous to capture rationale in the design context. Grudin 17notes that in certain development environments, exploring design space can be detrimental because it diverts critical resources. Additionally, many design decisions are considered in informal situations, where capturing the rationale is infeasible 29Tracking the location of where the rationale was recorded, the persons present at the time of design rationale capture, their roles and expertise, and the environmental context of the capture can help reviewers infer why specific information was considered.

Tacit Knowledge – Unintentional Omission

Tacit knowledge 25is a term used to describe things that we know, but are not able to bring to consciousness. It is possible that design rationale may unintentionally be omitted because a designer may not be able to explicate their tacit knowledge. Designers may not be able or willing to spend the energy to articulate their thoughts into the design rationale system, especially when they reach breakdowns, and are focusing on understanding and resolving the problem at hand. Conklin and Bergess-Yakemovic 7state that designers focus should be on solving problems and not on capturing their decisions. During routine situations, designers react to problems as they arise without consciously thinking about them. Collaborative design can aid in eliciting tacit knowledge through the articulation of reasoning to others in the design. However, this elicitation is necessarily costly to the designers, and will only bring out ideas that are pertinent to the current design problem, which is not necessarily what someone reviewing the rationale will need.

Representation – Unintentional Omission

Design rationale may also be omitted because of inappropriate representations. Rationale capture tools can involve varying degrees of human involvement, but regardless of the technique, the type of information captured is dependent on the representation of the rationale. Lee and Lai 20argue that design rationale inadequately captures domain expressiveness, resulting in people not being able to get the information they need out of design rationale. The Questions, Options, and Criteria notation was suggested by MacLean et al 22because it fits the natural discussions of design. Others have argued that design rationale should be focused around concrete problems to make deliberations more tangible 21

More comprehensive representations allow for more rationale to be captured, but the added effort to capture the rationale can shift the cognitive effort from the design process. More flexible notations, such as free text, are more difficult to index and utilize. Less intrusive techniques, such as capturing rationale during meetings, can ease problems associated with interrupting the design process. But, these techniques are likely to capture lesser amounts of rationale because designers may not be present at these meetings or contextual clues may not be present.

Communication through Omission

There are also situations where the designers may communicate information through omission. For example, a manager may ask anyone on the design team with experience in a particular programming language to contact her or him. In this situation, certain employees will communicate their inexperience with the programming language by not responding. However, it is entirely possible that certain individuals did not respond because of other reasons. People may also communicate their reasoning through silence when they disagree with a particular viewpoint, but do not want to appear confrontational. Design rationale systems do not adequately capture this information.

Incentive – Intentional Omission

There are situations where designers feel it is advantageous not to record their rationale. Design environments are constrained by time and organizational constraints 29Designers who are constrained by time will need to prioritize which deliberated upon information to articulate. Often design deliberations under strict deadlines only discuss specific matters that are viewed by the designer as highly significant at the time.

Sharing knowledge can be detrimental to designers, especially if the information they share could potentially be used against them. Designers may be hesitant to simply give away knowledge without knowing who will use it or how it will be used. Rewarding knowledge sharing is a challenging task that involves creating tangible rewards for intangible ideas. This is especially difficult considering that there is often no way to evaluate which ideas resulted in the success or failure of an artifact.

Moreover, the time spent exhaustively searching design space and recording design rationale may cause designers to miss windows of opportunity 17It is therefore important to lessen the cost to designers in capturing rationale. However, removing the cost of design rationale capture is not always possible. And, reducing the costs to designers often displaces it to the reviewers who then may not be able to utilize the rationale because it is incomplete or inaccurate.

Cost and Benefit – Intentional Omission

Complex design is normally a group activity, and tools to support designers can therefore be considered a type of groupware. Grudin 16describes several problems involved in developing groupware. Specifically, one of the obstacles he discusses is of particular interest to design rationale systems. He contends that there should not be a disparity between who incurs the cost and who receives the benefit. If the focus of design rationale is placed only on minimizing the cost to later users, it can add significant costs to the original designers. A major shortcoming in design rationale is the failure to minimize the cost to the original designers. Gruber and Russell 15contend that design rationale must go beyond the *record and replay* paradigm and collect data that can benefit later users, while also not being a burden on designers. But, it is also important that design rationale provide a net benefit to the design process. And, capturing incomplete rationale can harm the design process if reviewers make inaccurate inferences based on the rationale.

Privacy and Security – Intentional Omission

In certain contexts, there are privacy and security concerns with the design rationale. For instance, organizations may want to keep their rationale secure so that competing organizations cannot gain a competitive advantage. Similarly, there may be political repercussions or security breaches if policy makers make their rationale available to the public. For example, designers may not want to document all of their considerations because politically motivated information could be held against them. There are also situations where people working outside the specified work procedures may not want to document their work-arounds in fear that it will be detrimental to them. Designers may not want to capture rationale that could be viewed as detrimental to themselves or certain other people, and therefore will intentionally omit certain rationale. Additionally, individual designers may not want their design considerations to be available for post-hoc scrutiny. Therefore, it is important to give designers a sense of security, and implement privacy and security features into rationale tools.

Retrieval Limitations

Karsenty 18evaluated design documents and found that design rationale questions were by far the most frequent questions during design evaluation meetings. However, only *41%* of the design rationale questions were answered by the design rationale documentation. The reasoning for the discrepancy between the needed and captured design rationale is broken into several high-level reasons, including analysts not capturing questions, options, or criteria; the inadequacy of the design rationale method; and the lack of understanding. Other literature has focused on several issues that contribute to this failure, including inappropriate representations 202122the added workload required of designers 717exigent organizational constraints 29and contextual differences between the design environment at the time when the rationale is captured and the time when it is needed 15

Relevance

Initial designers and subsequent users of rationale may have different notions of what is relevant in a given design context. Wilson 36describes relevance as a relationship between a user and a piece of information, and as independent of truth. Relevance is based on a user's situational understanding of a concern. Moreover, he argues that situational relevance is an inherently indeterminate notion because of the changing, unsettled, and undecided character of our concerns. This suggests that the rationale constructed at design time may not be relevant to those reviewing the rationale at a later time in a different context. When rationale is exhaustively captured, there is an additional effort required to capture the information. And, when too little information is captured, the reviewers' questions remain unanswered.

Belkin 3describes information retrieval as a type of communication whereby a user is investigating their state of knowledge with respect to a problem. Belkin contends that the success of the communication is dependent upon the extent to which the anomaly can be resolved based on the information provided, and thus is controlled by the recipient. This suggests that designers cannot recognize the relevance of rationale until a person queries it. And, later uses may not be able to specify what information will be most useful, but rather will only recognize that they do not have the necessary knowledge to resolve a problem.

Indexing

A more structured representation can make it more difficult to capture design ideas, but can facilitate indexing and retrieval. One problem is that there is an inherent tradeoff between representational flexibility and ease of retrieval. Unstructured text is easier to record, but more difficult to structure in a database. One solution is to push the burden on to those who are receiving the benefit 16which would be the retrievers in this case. However, if

the potential users of the rationale find the system to be too effortful, then it will go unused. Then, designers will not be inclined to spend time entering design rationale into a system that will not be used.

Usage Limitations

People reviewing design rationale have a goal and a task at hand that they hope the design rationale will support. Often, these people are also involved in designing. If this is the case, the reviewers may not know whether retrieved rationale is applicable to their current problem.

Uniqueness

Because design problems are unique, even rationale that successfully resolved one design problem may not be applicable to a different problem. In addition to the problem of accurately and exhaustively capturing rationale, recognizing the impact of rationale can be a difficult task.

Understanding rationale tied to one problem could help resolve similar problems in the future. However, design is contextual, and external factors often interact with the design activity in a complex and unexpected manner. Therefore, designers must consider the holistic effects of external factors. Reviewers of rationale are interested in understanding information to help them with their task-at-hand, and without understanding the context of those problems, utilization of the information becomes difficult. The inherent problem of identifying the impact of rationale across different design problems adds a net cost to utilizing rationale, decreasing the overall utility in the design process.

Measuring Effectiveness

Norman 24states that systems need to bridge the *gulf of evaluation.* The gulf of evaluation refers to the effort involved in identifying how well the expectations of a system have been met. Bridging the gulf of evaluation involves giving users feedback on whether their actions have moved them closer to achieving their goal. One problem with design rationale systems is that there is no absolute measure of effectiveness. A design rationale system can give users feedback to indicate that the information was stored, but this does not necessarily mean that the system was effective. An inherent problem in using design rationale to support temporally distributed designers is that the designers will not immediately know what rationale will be most useful. Because of the complex nature of design, it may never be possible to evaluate the impact of rationale.

Organizational Limitations

Design Challenges. As Davenport and Prusak warn in their book 9“if you build it, they may not come." Being able to build a system is only an initial step; the “gold standard” against which success is measured, however, is whether people will accept and use it. As system builders, we not have much control over the personal reward systems of the individual users and management mandate that many 926recommend will enhance usage of the technology, and therefore we can not motivate our users as such. Therefore, we must rely on other factors.

Following Grudin's suggestion 16we need to design systems so that there are identifiable benefits to the people who use them. When an individual uses a system, the benefit gained from this experience should encourage her or him to continue using the system. We must strive to design systems in such a way that there are benefits to the current users, not just the future users. In doing so, the system will have a better chance of sustaining continued use.

Design rationale tools must support both formal and informal knowledge, making the system flexible enough so that broad content types were supported 8They must support multiple levels of organization of content and design systems so that knowledge can be structured at any time after it is entered 30 We do not want to force the content to be too structured but need to provide structuring mechanisms so that it can be automatically structured or restructured at a later time.

As Grudin suggested 16it is best to build upon an already successful application. The luck, of course, is in finding such an application, and in appropriately determining “successful.” Building on an application that the user population is already familiar with reduces the overhead of learning to use a new system 37Providing a totally new application for storing and retrieving information increases overhead and correspondingly decreases the probability of a successful system introduction.

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TRANSCENDING THE BARRIERS

We noted in the introduction that there are three primary goals of design rationale systems—communication, reflection, and analysis. Regardless of the design perspective that is adopted, these three goals hold. The previously described cognitive, capture, retrieval, and usage limitations do not equally impact each goal. The impact of each barrier on these goals is discussed below.

Reflection

Supporting reflection involves transcending the barriers associated with communicating ideas while in the act of designing, using overly restrictive frameworks to structure thinking, and prioritizing what to reflect upon.

Design rationale provides structure and framework that can be used to reflect upon the design process or resulting artifact. But design rationale can also distract from design activities if the emphasis of design rationale is on

recording for other people, rather than supporting the current design activities. The problem with using design rationale as both a reflective tool and a communication tool is that these goals tend to conflict at times, especially if there is significant effort needed in the communication. In these cases, design rationale can distract from reflection. To move beyond these barriers, it is important that design rationale systems facilitate communication with little effort during the design process and are focused on supporting specific and non-conflicting goals.

Brown and Duguid 5note that a focus on information alone can cause context, background, history, common knowledge, and social resources to be ignored when envisioning solutions to problems. They note that "attending too closely to information overlooks the social context that helps people understand what that information might mean and why it matters" (pg. 5). And, viewing problems in a less restricted view can offer "alternatives, breadth of vision, and choices" (pg. 1).

Using design rationale schemas that are focused on specific aspects of arguments may overly focus thoughts on aspects that may not be the most vital to design deliberations. It is therefore important to prioritize what items to reflect upon. Sometimes it is more important to think about the *what*, *where*, *who*, or *when* aspects of design rather than the why. In these cases, it may be more appropriate to reflect on usage scenarios, design patterns, or project management constraints. Research into how to integrate design rationale with other reflective activities would help make design rationale systems more useful.

Communication

As a communication tool, design rationale systems provide both structure and availability. The degree to which structure is utilized to focus communication varies. Systems can range from requiring specific fields of information to be completed (e.g. questions, criteria, etc.) to having designers record their deliberations in free-form notation. In any case, the structure provides a framework within which designers can effectively focus their communication. Availability refers to how many people have access to communications. Fischer 12argues that much of the design work is done through evolutionary redesign, and long-term collaboration is essential. Long-term collaboration requires designers at one time to communicate with designers at another time. Written notes, letters, diagrams, photographs, electronic mail, and databases all record information that can later be reviewed. In the next subsection, we will differentiate various modes of communication and suggest which may be appropriate in different situations.

Alternate Means of Communication

Communication can be classified based on its levels of structure and availability. Some communications are stored for extended periods of time and can be reviewed by anyone. Other communications take place informally between a limited number of people.

Informal conversations between designers occur through telephone calls, face-to-face conversations, before and after meetings, and through instant messaging tools. These communications are useful for designers because they can share ideas and gather feedback about what others think about the reasoning behind design decisions, while still having a certain degree of privacy and security.

These informal communications can also be captured for later review by integrating design rationale tools into web browsers, e-mail clients, phone systems, instant messaging tools, and meeting support tools. Communications can also be structured, yet remain unrecorded. Meetings may be follow formal processes, and brainstorming strategies structure processes for identifying a wide range of alternatives.

Social communities offer another form of availability. Designers can share ideas within a social community, where other designers can freely share that information. Social communities in software engineering are composed of both Communities of Practice (CoP) and Communities of Interest (CoI) 35Communities of Interest are heterogeneous social groups with different backgrounds and work activities all collaborating on a single problem. Fischer 12notes that CoP are associated with problems and learning when answers are known, and CoI are associated with ill-defined problems when answers are not known.

Muller and Carey 23note that one difficulty in supporting designers through CoP is that designers are often the sole practitioners of their discipline within a multi-functional team. When designers are acting as sole practitioners, social communities may not be the appropriate outlet to make informal communications available.

Choosing a Mode of Communication

There are a number of factors that influence the amount of structure that should be used in communication.

When the primary goal of a design rationale system is to support reflection, using temporary communication media may be more appropriate. And, it may not be advantageous to track preliminary and non-critical decisions that take place in design processes, even when the goal is to support temporal communication.

Structured communications may be useful for focusing arguments among designers with different goals. However, when privacy, security, or the risks of misinterpretation are important, steps should be taken to make the rationale less available. In these cases, it may be appropriate for DR systems to support multiple types of communication, whereby designers can choose what

information to make available. Similarly, supporting both informal and formal representations of rationale are useful when structuring rationale could hinder the design process 30

When the reason for structuring design rationale is to support later analysis, the information should be structured based on the analysts' needs. When the structuring is intended to provide a framework for communication, it is important to identify a structure that will best focus the communication.

Analysis

When design rationale is captured and structured, it can be utilized by those outside of the design context to analyze artifacts and the influence of the decisions made in the process of designing the artifact. Effective use of design rationale as an analysis tool requires an accurate depiction of the design process.

Causal analysis in design is difficult, if not impossible, due to the wicked nature of design problems. The same process can lead to different results in different environments. Because of the complexity of design processes, the influence of decisions can never be completely known. Design rationale can be used to identify factors that *could* have led to failures or successes; however, because of the complex nature of design, it is possible that the decisions may not have been very influential.

Therefore, any analysis of design processes should not overemphasize the influence of the captured decisions. It is possible that the effects were caused by other factors. This barrier can be diminished by using additional tools and methods when analyzing design processes. Design rationale is only one tool for analyzing design processes and artifacts, and only shows a small part of the total activity. Other methods, such as ethnography, interviews, quantitative analyses of a project's cost, and measures of success can be used in conjunction to gain a fuller picture of the design process.

CONCLUSIONS

In this paper we have looked at a number of barriers that impede design rationale as an effective tool for reflection, communication, and analysis. The barriers were discussed in terms of cognitive, capture, retrieval, usage, and organizational limitations.

At one level, the intent of design rationale is to transmit information from a designer working at one time and in one context to another designer working in another time and context. This is the most frequently-cited goal in design rationale research. But, is this the ultimate goal of design rationale? We argue that it is not. The goal of research on design rationale is to improve the quality of designs. There are fundamental barriers to developing information systems that support asynchronous communication among designers working on different design problems. Therefore, design research should focus on supporting designers who better understand the context of their unique problems.

The goal of research on design rationale is to improve the quality of designs. There are fundamental barriers to developing computer systems that support communication among designers working on design problems. Therefore, the focus of design rationale should be on identifying what tools are most appropriate for the task. Using less persistent modes of communication, putting a greater emphasis on supporting design processes rather than design tools, and creating systems that are optimized for a single purpose are necessary steps for improving design.

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