3 Effective Design Rationale: Understanding the Barriers

J. Horner, M.E. Atwood

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 this chapter, 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.

Keywords: design rationale, design theory, information retrieval

3.1 Introduction

Design is a goal-oriented process aimed at solving problems, meeting needs, improving situations, or creating something new or useful [8]. Design rationale (DR) is the reasoning and argumentation that underlies the activities that take place during the design process. DR tools are intended to support various design activities. In upstream design activities, where vague requirements are translated into concrete system specifications, DR schemas can provide a framework with which one can carefully reflect upon design decisions. Structuring design arguments also provides a mechanism by which people with different goals can communicate their positions on design issues. People involved in maintenance or redesign activities can use the documentation produced to avoid spending time reconsidering decisions that have been previously considered. This record 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 [25]. DR systems are primarily intended to support communication, reflection, and analysis in design. DR systems provide support at various phases of design, including conceptual design, detail design, implementation, and maintenance. And, DR is used in a variety of design domains. In some situations, DR is the appropriate tool for the task;

however, it may not be in other situations. In this chapter, we will discuss many of the challenges that have impeded the ability for DR to effectively support designers.

3.2 Design Perspectives and Rationale

DR 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 DR 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 [2] so the following paragraphs will briefly describe some of the diverse views.

3.2.1 Symbolic Information Processing

Simon [26] viewed 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 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* [26]. Rather than exhaustively considering design issues, people choose satisfactory solutions based on the information available.

The argumentation structure of DR 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 project.

However, it is often impossible to identify causal relationships in design because of the subtle factors that can influence the effectiveness of design projects. Recording DR creates the opportunity for people to perform a post hoc analysis of design decisions. Designers are constrained by the amount of information they can process. Because of this, they may be hesitant

to record decisions that could later be scrutinized by people with more information at their disposal.

3.2.2 Wicked Problems

Rittel and Weber [21] dissented 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 is 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 collective understanding of how to explain a problem.

Issue-based information system (IBIS) was developed by Rittel as a means to structure this argumentation. In this sense, DR is intended to support collaborative design that involves designers with differing goals and perspectives. The structure afforded by DR provides a mechanism for designers to communicate their diverse thoughts with other designers working on the same task.

The primary benefit of DR from this perspective is that it can act as a collaborative communication tool. In fact, the unique nature of planning problems would present a potential barrier to the reuse of DR by students of designers and persons working on other projects. Still, the DR 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.

3.2.3 Situated Action

Schön [22] describes 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 they receive 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, DR can help designers reflect on what may have resulted in the problem. Tracking the associated DR would help to 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 DR is used to support reflection, the efforts in recording these aspects are minimal.

Incremental formalization [24] is the process of gradually translating informal rationale into formal notations. Incremental formalization allows designers to easily capture DR in the act of designing and later come back and formalize the information into a DR 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 DR systems should support efficient identification of solutions or reflective understanding of the problem.

3.2.4 Patterns

Alexander [1] describes 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 and city planning domains as "timeless" solutions that resolve the forces in a given area.

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 in a given environment can help give early insight into the success or failure of a solution.

However, Alexander argues that patterns depend on stability, not purpose (p. 119). He argues this point by comparing the streets in Greek villages to cafés in Los Angeles. In Greek villages there are whitewashes outside every house to allow people to set up chairs and contribute to the street life, while the cafés in Los Angeles are indoors away from the sidewalk so the food does not get contaminated. Alexander argues that while both of these patterns have purpose, only the Greek villages are *alive* and self-sustaining. Villagers keep the whitewashes clean "because it is deeply

connected to their own experience" (p. 120). The Los Angeles cafés are not *alive* because the pattern is forced by law. The pattern will change when the law is changed because people want to be outdoors on a spring day. Alexander's point is that the purpose of a solution is not as important is its stability because solutions that do not naturally resolve the conflicts will eventually fail.

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.

3.2.5 Implications

A brief analysis of these diverse perspectives on design helps to clarify the theoretical underpinnings of potential DR benefits, and also illuminate several potential barriers that impede the effective utilization of rationale. Table 3.1 summarizes the benefits and barriers to using DR that can be inferred from each of the four previously described design perspectives.

Table 3.1. Theoretical implications

theory	positive implications	potential barriers
symbolic information processing	DR can focus cognitive energy and provide reviewers an opportunity to view what considerations were given the most attention.	additional issues increase the complexity of a design problem, and, DR allows for a post-hoc analysis of decisions by people with more information than initial designer
wicked problems	DR Structure support integration of issues by people with different perspectives.	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. And, 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.

3.3 The Fundamental Barriers

DR systems are intended to help support reflection, communication, and analysis. However, there are numerous barriers that hinder the effective use of DR for these purposes. In this chapter, we classify these barriers into four categories:

- Cognitive limitations
- Capture limitations
- Retrieval limitations
- Usage limitations

3.3.1 Cognitive Limitations

People have a limited capacity to process information. This limitation can hinder the effectiveness of DR. Simon [26] states that our rationality is bounded and we 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, DR is necessarily incomplete.

What Was not Considered

It is important to recognize the potential for unintended consequences, especially in systems where the risks are high [27]. In 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?" DR 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.

In order to use DR to identify what is missing, there must be a mechanism to relate projects to other projects that are most similar. It is also important that there is a large enough base of rationale to ensure that there will be enough comparable design projects. And, it is necessary to represent the information so that the most pertinent missing information is easily identifiable.

Added Complexity

One mechanism to more exhaustively analyze the design space is to use collaboration in the design process [6]. However, in any collaborative

design context, maintaining conceptual integrity is important to keep the design project focused [4]. More 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 [26] also notes that we are unable to exhaustively consider all possible alternatives, so we choose options that are satisfactory. Even if DR can effectively elicit additional issues, designers will not be able to spend more time reflecting on each issue. Therefore, it is important that DR be used to help designers think about the right issues. In situations where there are different viewpoints as to which of several alternative solutions should be used, reflecting on the *why* aspects of design can help identify better solutions. However, in situations where solution ideas are still being formulated, it may be better be spend time thinking about what options are possible rather than why each option is appropriate.

Groupthink

One goal of DR is to support collaboration among designers. A problem with collaborative design is that when poor processes are followed, teams may quickly arrive at a poor solution and focus the rest of their energy on relatively insignificant issues. Janis [13] termed this phenomenon *group-think*, and noted that highly cohesive teams working on complex designs under strict deadlines where it is important to arrive at a solution are most at risk to undergo this detrimental phenomenon.

If designers used DR to explicitly structure their conversation around the issues that are most important to decision-making, they would be less likely to make poor decisions. However, a tool alone will not necessarily result in better design processes. If DR tools are used to support reflection, how the tool can be used to support good design processes should be emphasized. It is important that tools support and enhance good work practices, but should not be expected to change poor practices.

3.3.2 Capture Limitations

There are two different situations in which DR may not be captured. In one case, the omission is unintentional. In the other, it is quite intentional. We consider both.

Capturing Rationale in Context

DR may be considered, but unintentionally not recorded by the capture process. There are several reasons why considerations could be unintentionally omitted from DR. If the DR 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 [11] notes 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 [23]. Tracking the location of where the rationale was recorded, the persons present at the time of DR capture, their roles and expertise, and the environmental context of the capture can help reviewers infer why specific information was considered.

Tacit Knowledge

Tacit knowledge [20] is a term used to describe things that we know, but are not able to bring to consciousness. It is possible that DR 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 DR system, especially when they reach breakdowns and are focusing on understanding and resolving the problem at hand. Conklin and Burgess-Yakemovic [6] state 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

DR 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 [15] argue that design rationale inadequately captures domain expressiveness, resulting in people

not being able to get the information they need out of DR. The Questions, Options, and Criteria notation was suggested by MacLean et al. [17] and was argued to better fit the natural discussions of design. Others have argued that DR should be focused around concrete problems to make deliberations more tangible [15].

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. DR systems do not adequately capture this information. It may be useful to link rationale with the generating designer and method of capture.

Incentive

There are situations where designers feel it is advantageous not to record their rationale. Design environments are constrained by time, costs, and changing personnel [23]. Designers 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 DR may cause designers to miss windows of opportunity [11]. It is therefore important to lessen the cost to designers in capturing rationale. However, removing the cost of DR 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

Complex design is normally a group activity, and tools to support designers can therefore be considered a type of groupware. Grudin [10] describes several problems involved in developing groupware. Specifically, one of the obstacles he discusses is of particular interest to DR systems. He contends that there should not be a disparity between who incurs the cost and who receives the benefit. If the focus of DR is placed only on minimizing the cost to designers, it can add significant costs to the reviewers. A major shortcoming in DR is the failure to minimize the cost to reviewers. Gruber and Russell [9] contend that DR must go beyond the record and replay paradigm, and collect data that can benefit reviewers, while also not being a burden on designers. But, it is also important that DR 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

In certain contexts, there are privacy and security concerns with the DR. 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.

3.3.3 Retrieval Limitations

Karsenty [14] evaluated design documents and found that DR questions were by far the most frequent questions during design evaluation meetings. However, only 41% of the DR questions were answered by the DR documentation. The reasoning for the discrepancy between the needed and captured DR is broken into several high level explanations, including analysts not capturing questions, options, or criteria, the inadequacy of the DR method, and the lack of understanding. Other literature has focused on several issues that contribute to this failure, including inappropriate representations [15, 17] the added workload required of designers [6, 12] exigent organizational constraints [23] and contextual differences between the design environment at the time when the rationale is captured and the time when it is needed [9].

Relevance

Initial designers and subsequent users of rationale may have different notions of what is relevant in a given design context. Wilson [29] describes 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 [3] describes 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, reviewers 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 [10] which would be the retrievers in this case. However, if the potential users of the rationale find the system to be too effortful, it will go unused. Then, designers will not be inclined to spend time entering DR into a system that will not be used.

3.3.4 Usage Limitations

People reviewing DR have a goal and a task at hand which they hope the DR will support. Often, these people are also involved in designing, or resolving ill-defined problems. 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 multiple subproblems. Therefore, designers must consider the holistic affects 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. These costs should be evaluated against the overall payoff of using the rationale.

Measuring Effectiveness

Norman [19] states 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 DR systems is that there is no absolute measure of effectiveness. A DR 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 DR 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.

3.4 Transcending the Barriers

We note that there are three primary goals of DR systems, which are reflection, communication, and analysis. The previously described cognitive, capture, retrieval, and usage limitations do not equally impact each goal. The impact of each barrier is influenced by many factors, including the goal of the system and the social system in which the system is used.

3.4.1 Reflection

Reflection is a goal of many DR systems, and supporting this goal 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.

DR provides a framework that can be used to reflect upon the design process or resulting artifact. But DR can also distract from design activities if the emphasis of DR is on recording for other people, rather than supporting the current design activities. The problem with using DR 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, DR can distract from reflection. To move beyond these barriers, it is important that DR systems facilitate communication with little effort during the design process. DR systems should focus on supporting one primary goal. If the goal of a DR system is to support reflection, features that are used for documenting the rationale should be either eliminated or extremely nonintrusive.

Brown and Duguid [5] note caused 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" (p. 5). And, viewing problems in a less restricted view can offer "alternatives, breadth of vision, and choices" (p. 1).

Using DR 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 [13, 31]. In these cases, it may be more appropriate to reflect on usage scenarios, design patterns, or project management constraints. Research into how to integrate DR with other reflective activities would help make DR systems more useful.

3.4.2 Communication

As a communication tool, DR systems provide both structure and availability. The degree of structure refers to the variation flexibility that a system allows. And, the availability refers to how many people have access to communications. DR systems 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. Fischer [7] argues 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 designer at another time. Written notes, letters, diagrams, photographs, electronic mail, and databases all record information that can later be reviewed. In Sect. 3.4.3, 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 DR 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 following 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) [28]. Communities of interest are heterogeneous social groups with different backgrounds and work activities all collaborating on a single problem. Fischer [7] notes that CoP more often deal with problems where the answers are known, and CoI are associated with ill-defined problems where there is no one right answer.

Muller and Carey [18] note that one difficulty in supporting designers through CoP is that designers are often the sole practitioners of their discipline within a multifunctional 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 DR system is to support reflection, using nonintrusive systems is more appropriate. And, it may not be advantageous to track preliminary and noncritical 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 [24].

When the reason for structuring DR 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.

3.4.3 Analysis

When DR is captured and structured, it can be utilized by those outside the design context to analyze artifacts and the influence of the decisions made in the process of designing the artifact. Effective use of DR 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. DR 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 place a heavy emphasis on 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. DR 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, and 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.

3.5 Conclusions

In this paper, we have looked at a number of barriers that impede DR as an effective tool for reflection, communication, and analysis. The barriers were discussed in terms of cognitive, capture, retrieval, and usage limitations. It is possible that the rationale was not considered, it was considered but either intentionally or unintentionally unrecorded, it could be recorded but not retrieved or it could be retrieved but not effectively applied.

One intent of DR is to transmit information from a designer working at one time and in one context to another designer working at another time and context; and, a second intent is to facilitate communication among designers working at the same time. The goal of research on DR 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 DR 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.

References

[1] Alexander C (1979) The Timeless Way of Building. Oxford University Press, Oxford
[2] Atwood ME, McCain KW, Williams JC (2002) How does the design community think about design? In: Symposium on Designing Interactive Systems, pp. 125–132
[3] Belkin N (1980) Anomalous states of knowledge as a basis for information retrieval. Can. J. Inform. Sci., 5: 133–143
[4] Brooks FP (1995) The Mythical Man–Month: Essays on Software Engineering. Addison-Wesley, Reading, MA
[5] Brown J, Duguid P (2000) The Social Life of Information. Harvard Business School Press
[6] Conklin J, Burgess-Yakemovic KC (1991) A process-oriented approach to design rationale. Hum.–Comput. Interact., 6(3–4): 357–391
[7] Fischer G. (2004) Social creativity: Turning barriers into opportunities for collaborative design. In: Proceeding from Participatory Design Conference, pp. 152–161
[8] Friedman K (2003) Theory construction in design research: criteria: approaches, and methods. Des. Stud. 24(6): 507–522
[9] Gruber T, Russell D (1996) Generative design rationale. Beyond the record and replay paradigm. In: Moran TP, Carroll JM (eds.) Design Rationale: Concepts, Techniques, and Use. Lawrence Erlbaum Associates, Mahwah NJ
[10] Grudin J (1994) Groupware and social dynamics: eight challenges for developers. Commun. ACM 37(1): 92–105
[11] Grudin J (1996) Evaluating opportunities for design capture. In: Moran TP, Carroll JM (eds.) Design Rationale: Concepts, Techniques, and Use. Erlbaum Associates, Mahwah NJ
[12] Herbsleb JD, Kuwana E (1993) Preserving knowledge in design projects: What designers need to know. In: Proceedings of Human Factors in Computing Systems, pp. 7–14
[13] Janis IL (1972) Victims of Group Think: A Psychological Study of Foreign Policy Decisions and Fiascos. Houghton-Mifflin, Boston MA

[14] Karsenty, L (1996) An empirical evaluation of design rationale documents. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM, New York, pp. 150–156
[15] Lee J, Lai KY (1991) What's in design rationale? Human–Computer Interaction 6(3-4): 251–280
[16] Lewis C, Reiman J, Bell B (1996) Problem centered design for expressiveness and facility in a graphical programming system. In Moran TP, Carroll JM (eds.) Design Rationale: Concepts, Techniques, and Use. Lawrence Erlbaum Associates, Mahwah NJ, pp. 147–183
[17] MacLean A, Young RM, Bellotti VME, Moran TP (1991) Questions, options, and criteria: Elements of design space analysis. Hum.–Comput. Int. 6(3–4): 201–250
[18] Muller MJ, Carey K (2002) Design as a minority discipline in a software company: Towards requirements for a community of practice. In: Proceedings from CHI, ACM, New York, pp. 383–390
[19] Norman DA (1990) The Design of Everyday Things. Doubleday, New York
[20] Polanyi M (1966) The Tacit Dimension. Doubleday, New York
[21] Rittel H, Weber M (1984) Planning problems are wicked problems. In: Cross N (ed.), Developments in Design Methodology, Chichester. Wiley, New York, pp. 135–144
[22] Schön DA (1987) Educating the reflective practitioner: toward a new design for teaching and learning in the professions. Jossey-Bass.
[23] Sharrock W, Anderson R (1996) Synthesis organizational innovation and the articulation of design space. In: Moran TP, Carroll JM (eds.) Design rationale: Concepts, Techniques, and Use. Lawrence Erlbaum Associates, Mahwah NJ
[24] Shipman F, McCall R (1999) Incremental formalization with the hyper-object substrate, ACM Trans. Inform. Syst. 17: 199–227
[25] Buckingham Shum S, Hammond N (1994) Argumentation-based design rationale: What use at what cost? Int. J. Hum.–Comput. Stud. 40(4): 603–652
[26] Simon HA (1996) The sciences of the artificial, MIT Press, Cambridge MA
[27] Tenner E (1996) Why things bite back: technology and the revenge of unintended consequences. Vintage, New York
[28] Wenger E (2002) Cultivating communities of practice: A guide to managing knowledge. Harvard Business School Press, Cambridge MA
[29] Wilson P (1993) Situational relevance, Info Stor Retrieval, 9: 457–471
[30] Wolf C, Karat, J (1997) Capturing what is needed in multi-user system design: Observations from the design of three healthcare systems. In: Proceedings from DIS, ACM, New York, pp. 405–415